https://doi.org/10.37434/tpwj2020.02.07

PROPERTIES OF JOINTS OF V1341T GRADE ALLOY UNDER THE CONDITIONS OF TIG WELDING

V.A. Koval, T.M. Labur and **T.R. Yavorska**
E.O. Paton Electric Welding Institute of the NAS of Ukraine
11 Kazymyr Malevych Str., 03150, Kyiv, Ukraine. E-mail: office@paton.kiev.ua

The paper presents the results of studying the weldability of sheet aluminium alloy of V1341T grade of Al−Mg−Si−Cu−Fe system under the conditions of manual nonconsumable electrode argon-arc welding. This alloy is characterized by high susceptibility to hot cracking in welding. The hot brittleness index is equal to A = 65.8–85.5 %. The impact of filler material chemical composition on hot cracking resistance of weld metal was studied. It is found that in welding by batch-produced wires of ZvAMg63, Zv1201, Zv1217 grades the crack resistance value is A = 30.3–53.9 %, and at application of wire of ZvAK5 grade this characteristic of welds is equal to A = 6.6–19.8 %. Manual nonconsumable electrode argon-arc welding of V1341T alloy allows producing tight sound joints of this material with strength coefficient of 0.80–0.87, which also depends on filler wire chemical composition. The average value of ultimate strength of the alloy welded joints, made using different grades of filler wire is equal to σ_t = 199.2–209.0 MPa, and the yield limit $\sigma_{0.2}$ = 136.6–147.6 MPa; relative elongation δ = 4.0–5.2 %, and bend angle α = 40–65 deg. 7 Ref., 4 Tables, 5 Figures.

K e y w o r d s : aluminium alloy, manual nonconsumable electrode argon-arc welding, filler wires, welded joints, structure, mechanical properties, hot cracks

Degree of technical excellence of flying vehicles is directly related to mastering new structural materials, which have higher technological characteristics in addition to strength. This allows manufacturing complex-shaped products. Such materials include multicomponent heat-hardenable alloy of V1341T grade (Al−Mg−Si−Cu−Fe alloying system). It also contains chromium and zirconium additives (Table 1). This alloy is designed for manufacture of typical elements of aircraft structures, namely hanging tanks, small tanks, cylinders and other products of a complex configuration, which are welded predominantly by the manual method [1].

Up to now, V1341T alloy was mainly welded by automatic methods. Investigations as to its manual welding were not performed at all, but alloy introduction into the aircraft industry for fabrication of shell-type complex-shaped structures makes urgent the investigations of its weldability under the conditions of nonconsumable electrode manual argon-arc welding.

The objective of the work was assessment of the main weldability characteristics of V1341T alloy under the conditions of nonconsumable electrode manual argon-arc welding, as well as establishing the technological possibilities of the alloy application in welded structures for aircraft construction. Selected as the weldability evaluation criteria, were the values of hot cracking resistance of weld metal and level of mechanical properties of the joints at application of fillers of different chemical composition, as well as determination of optimum conditions of sound weld formation.

Investigations were conducted on sheets 1.2 mm thick in T condition (quenching at 530 °C in water and natural ageing), which have the strength limit of 250−250.8 MPa.

The process of hot cracking in V1341T alloy under the conditions of manual nonconsumable electrode argon-arc welding was studied using «fishbone» type sample (Houldcroft samples) [2, 3]. Welding heating was performed from inverter type power source MW2000 of Fronius Company in the following modes: I_w = 54–56 A, U_a = 11.2–12.4 V. Technolog-

Table 1. Chemical composition of V1341T alloy and of the studied filler wires, wt.%

Wire grade	Mg	Mn	Cu	Si	Fe	Cr	Ti	Zr	Zn
V1341T, base metal	0.65	0.16	0.30	0.80	0.14	<0.10	0.03	<0.10	0.04
ZvAMg63	6.30	0.60	Traces	0.05	0.05	−	0.04	0.25	−
ZvAK5	−	−	0.15	5.60	0.24	−	0.12	−	−
Zv1201	0.02	0.30	6.50	0.08	0.12	−	0.12	0.15	0.04
Zv1217	−	−	10	0.02	0.04	Sc = 0.15	0.10	0.24	−

V.A. Koval — https://orcid.org/0000-0001-5154-1446, T.M. Labur — https://orcid.org/0000-0002-4064-2644,
T.R. Yavorska — https://orcid.org/0000-0003-2016-6289

© V.A. Koval, T.M. Labur and T.R. Yavorska, 2020

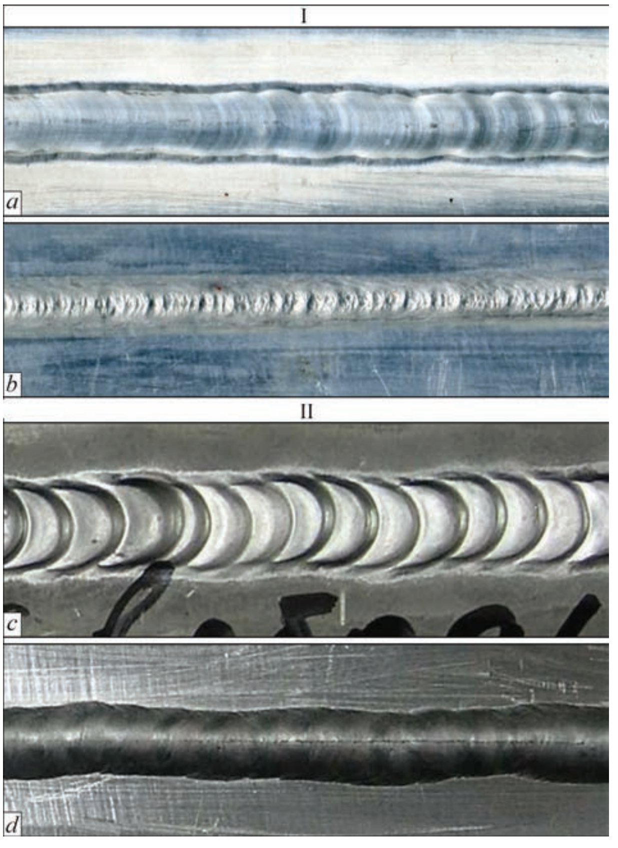

Figure 1. Appearance of face surface (*a*, *c*) and weld root (*b*, *d*) of welded joints of V1341T alloy, produced by manual arc welding without (I) and with filler wire application (II)

ical heating of V1341T alloy revealed its high sensitivity to hot cracking. The hot brittleness index in manual welding of this alloy without wire application was at a rather high level A = 65.8–85.5 %, that may be indicative of formation of an eutectic under the welding conditions and increase of the solidification range, as a result of lowering of the nonequilibrium solidus temperature [2, 3]. Results of testing 7–9 samples showed that formation of the main crack occurs in the weld center.

Table 2. Hot brittleness index (A, %) of V1341T alloy joints, produced using fillers of different composition

Wire grade	Main alloying elements, wt.%			Crack length, L_{cr}, mm	Crack resistance value $A = L_{cr}/L_{samp}$, %
	Mg	Cu	Si		
ZvAMg63	6.30	–	–	34–49	25–61.8 / 45.4
Zv1201	–	6.50	–	23–49	44.7–64.5 / 54.9
Zv1217*	–	10	–	23–42	34.4–52.6 / 39.6
ZvAK5	–	–	5.6	5–15	5.9–19.8 / 9.5

*Sc = 0.15 wt.%.

It is known [1, 3] that one of the methods to increase the hot cracking resistance of aluminium alloys in welding can be application of filler wire, which differs from the base metal by its composition. Here, its function consists in creation in the weld pool central zone of a certain metal volume in the solid-liquid state with uniform mixing of alloying components, which is a broad temperature range. This promotes healing of cracks, which form in the weld metal during its solidification [2].

Usually, there exists the possibility of application of several filler wire grades for welding each aluminium alloy. Their selection depends on the requirements to technological characteristics of the base metal and its welded joints in the product, such as: hot cracking resistance, strength, ductility and corrosion resistance. At the same time, it is practically impossible to obtain welded joints with the highest values of all the characteristics, as the maximum values of each of them are achieved at a certain combination of alloying element composition, present in the initial metal and filler wire. In this connection, in welding aluminium alloys, either general purpose wire, which provides rather high levels of the main mechanical properties of welded joints, or wire, which guarantees increase of one of these characteristics at satisfactory values of others [4]. Final selection of filler wire grades is determined by the conditions of fabrication and operation of the welded structure. Therefore, we studied the effect of chemical composition of several batch-produced 2 mm filler wires of different grades: ZvAMg63, ZvAK5, Zv1201, and Zv1217 on weldability of V1341T alloy (see Table 1).

Full penetration butt joints were produced in optimum modes, in order to evaluate the crack resistance of weld metal and conduct mechanical testing of welded joints of V1341T alloy. Technological reinforcement and weld root were removed on them with the purpose of making «fishbone» samples in keeping with the generally accepted procedure [2]. After that, repeated melting was performed along the weld by a welding arc in the mentioned modes, using filler wires of the above mentioned grades. Appearance of the produced welds after welding is shown in Figure 1. Results of crack resistance evaluation are given in Table 2, which shows the main alloying elements, promoting lowering of hot brittleness in aluminium alloys.

Analysis of the results of testing 8 to 10 samples, produced using each filler wire, showed (see Table 2) that hot crack formation also proceeds in the weld central part in the form of one main crack (Figure 2). At application of ZvAMg63, Zv1201, and Zv1217 fillers the hot cracking susceptibility remains high (A = 39.6–54.9 %). In the authors' opinion, the

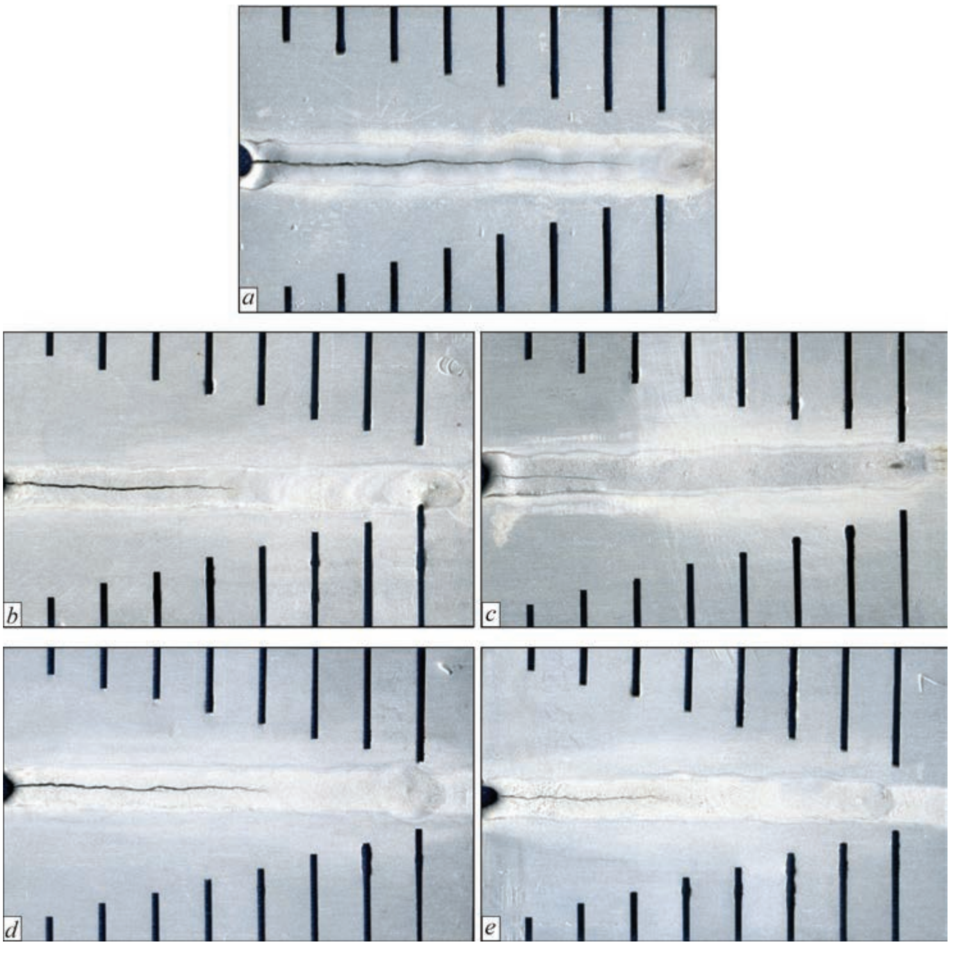

Figure 2. Hot cracking susceptibility of V1341T aluminium alloy 1.2 mm thick at manual nonconsumable electrode argon-arc welding, depending on filler wire chemical composition: *a* — without filer; *b* — ZvAMg63; *c* — ZvAK5; *d* — Zv1201; *e* — Zv1217

above-said can be associated with the presence of a significant quantity of low-melting eutectics based on Mg_2Si, which widen the temperature limits of the solid-liquid state of the metal and lead to increase of the extent of its shrinkage in the weld [5]. A positive effect was achieved at application of filler wire of ZvAK5 grade, containing up to 6 % silicon. Weld metal here has maximum values of crack resistance characteristic A = 5.9–19.8 %, compared to other wires. This occurs due to greater penetrability («healing» effect) of silicon-based eutectic [5, 6].

In order to determine the weld quality in manual nonconsumable electrode argon-arc welding, the welded joints were examined visually and using X-Ray inspection at standard sensitivity of 0.1 mm with further preparation of macrosections to study the nature of weld formation. X-Ray films were interpreted in «Densitomed» instrument, which allows determination of the metal density. Results of their analysis showed that no coarse defects classified as cracks, lacks-of-penetration, concentrated and scattered porosity of 0.5 mm and greater

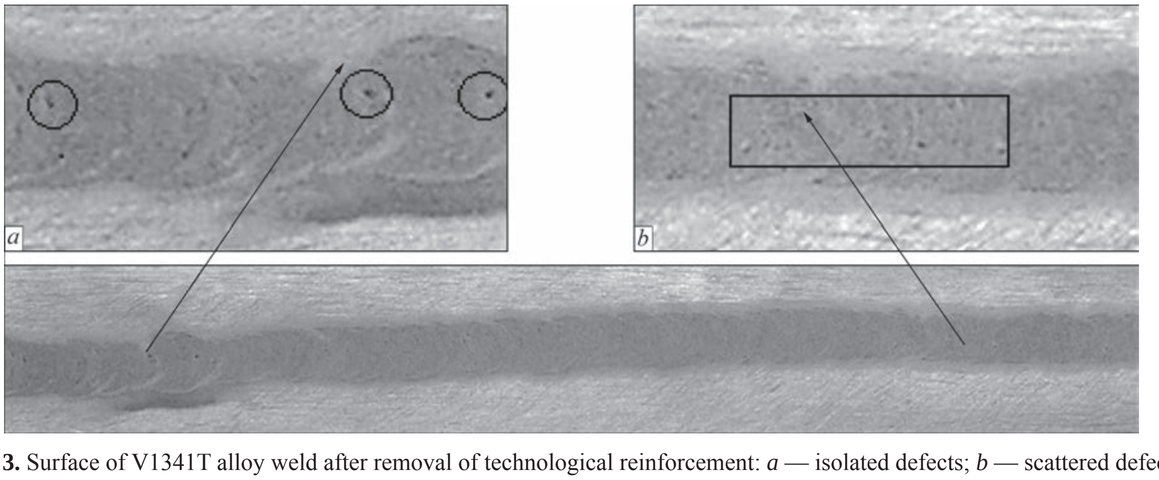

Figure 3. Surface of V1341T alloy weld after removal of technological reinforcement: *a* — isolated defects; *b* — scattered defects

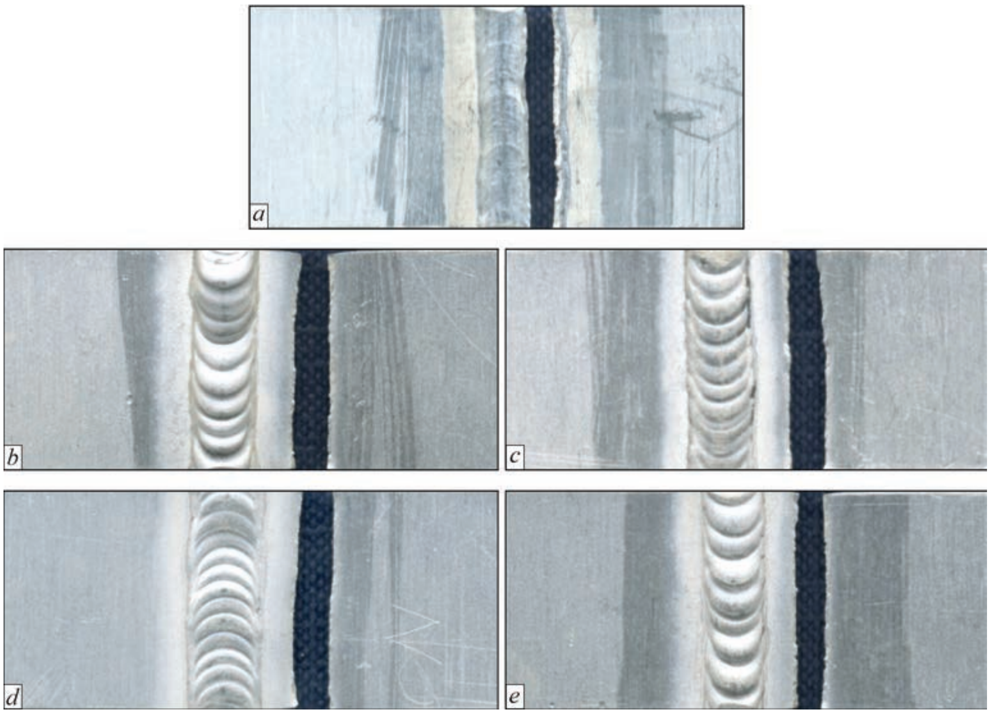

Figure 4. Fracture mode of samples of V1341T aluminium alloy 1.2 mm thick, produced by manual nonconsumable electrode welding, using different filler wire grades and without wire: *a* — without wire; *b* — ZvAMg63; *c* — ZvAK5; *d* — Zv1201; *e* — Zv1217

size are found in the joints. At visual examination of the weld surface after removal and grinding of the technological reinforcement, isolated scattered pores of up to 0.08 mm size are observed, that is 6 times lower that the admissible norms. The distance between the fine pores is equal to 11.0–15.0 mm, and the total extent is 7–8 mm on a weld section of 100 mm length (Figure 3). This is also two times smaller than the admissible values [7].

Geometrical parameters of the welds were determined by an electronic caliper APT-34460-150 with division value of 0.01 mm, and measurement accuracy of 0.03 mm. Measurement results showed (Table 3) that the optimum value of weld form factor, calculated

Table 3. Geometrical parameters and form factor of welds, produced in manual argon-arc welding of V1341T alloy (δ = 1.2 mm)

Symbols	Values of geometrical parameters of welds, mm		Weld form factor $K = \frac{B}{(b+\delta)}$
	minimum	maximum	
Weld width *B*	3.53−4.86	4.92−5.60	2.43
Weld root width *H*	3.15−4.15	4.2−5.1	
Technological reinforcement height *b*	0.23−0.7	0.8−1.3	
Weld root height *h*	0.17−0.68	0.85−1.15	

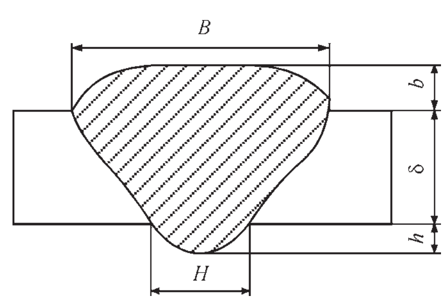

Table 4. Mechanical properties of welded joints of V1341T alloy 1.2 mm thick, made by manual nonconsumable electrode arc welding, using different grades of filler wires and without them

Filler wire grade	σ_t, MPa	$\sigma_{0.2}$, MPa	δ, %	α, deg	Strength coefficient
Without filler	125.3−153.3 139.0	110−144.6 130.0	0.7−1.4 0.9	30−37	0.55
ZvAMg63	196.3−207.1 199.9	141.2−144.1 142.7	3.6−5.4 4.5	55−60 58	0.8−0.82
ZvAK5	190.5−209.2 202	138.4−142.7 136.6	3.1−51.0 4.0	55−65 59	0.8−0.82
Zv1201	193.2−207.4 201.7	145.0−143.7 144.3	3.7−5.4 4.8	40−60 50	0.8−0.82
Zv1217	208.2−209.0 208.7	143.1−151.6 147.6	4.6−5.4 5.2	45−66 56	0.83−0.87

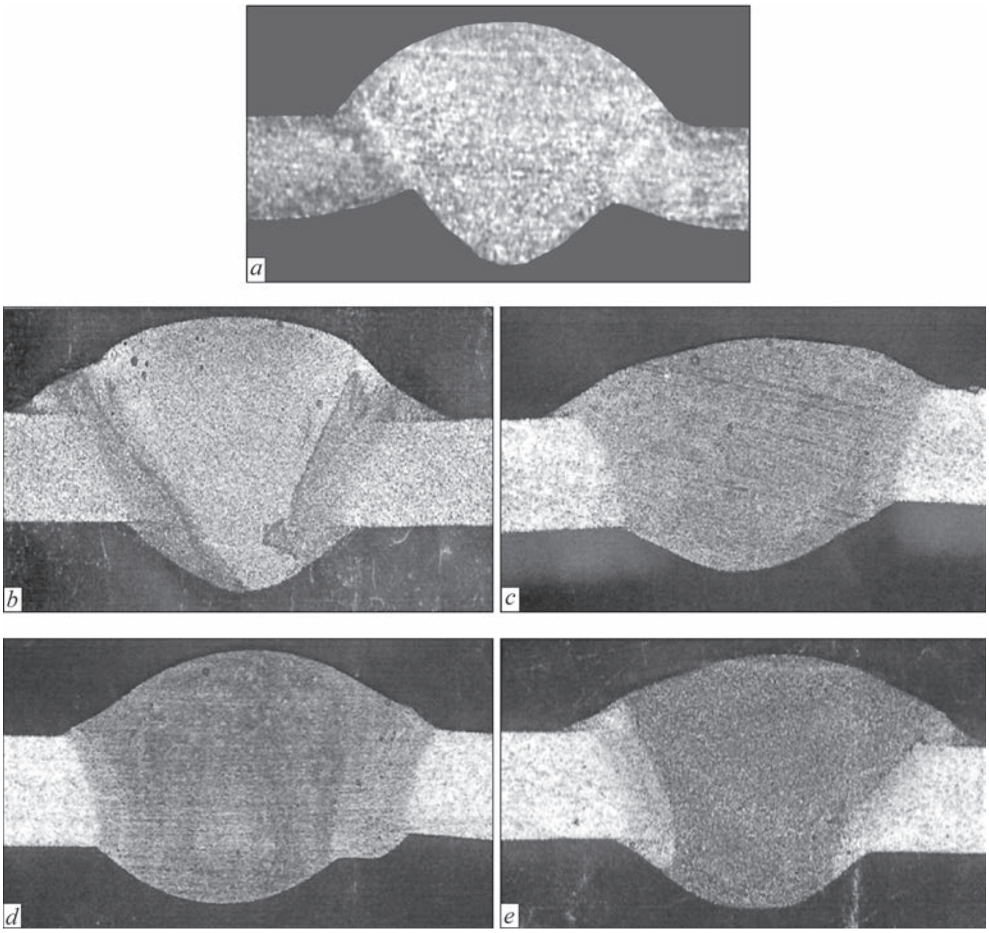

Figure 5. Microstructure of welded joints of V1341T alloy 1.2 mm thick, produced by manual nonconsumable electrode argon-arc welding without filler and using fillers of different grades: *a* — without filler; *b* — ZvAMg63; *c* — ZvAK5; *d* — Zv1201; *e* — Zv1217

by formula $K = 1(h + g)$, is 2.43 for the studied joints that corresponds to the admissible values, in keeping with normative documentation (GOST 14806−80).

Mechanical properties of welded joints of V1341T alloy were determined at testing standard samples for stretching and bending, which were cut out of butt welded joints. The samples had a technological reinforcement and weld root. Their fracture occurred along the HAZ at 3–5 mm distance from the fusion line (Figure 4). Results of mechanical testing showed that the ultimate strength and yield limit of the joints after welding are equal to σ_t = 200–208.7 MPa, $\sigma_{0.2}$ = = 136.6–147.5 MPa, irrespective of filler wire grade. The greatest values of relative elongation characteristic (δ, %) were obtained, when using filler wire of Zv1217 grade (Table 4). The strength coefficient of the weld here was equal to 0.83–0.84, compared to base metal value (σ_t = 250.8 MPa).

Ductility value α, obtained under the conditions of three-point bending of samples of a welded joint of V1341T alloy, produced with ZvAK5 and ZvAMg63 wires, is equal to 59–58 deg, respectively. In the case of application of filler wires Zv1201 and Zv1217, this welded joint characteristic is equal to 50 and 56 deg, respectively. The value of bend angle of all the welded joints decreases 4 to 6 times, compared to that of the base metal (α = 180 deg) (see Table 4).

For comparison with the mentioned joints, welds were made by manual argon-arc welding over «raised edges», i.e. without filler application (Figure 1, I). As shown by mechanical testing, such joints of V1341T alloy have low mechanical properties. The values of their ultimate strength and yield limit are smaller by 50, 30 MPa, compared to welds, produced using fillers. Values of relative elongation δ and bend angle α here decrease 4 and 2 times, respectively. The strength coefficient of the joint is equal to just 0.55 of that of the base metal (see Table 4). Deterioration of mechanical properties of welds, made without the filler, is, probably, due to the presence of stress raisers from weld root side, in the form of sharp-angled depressions in the zone of its fusion with the base metal and smaller cross-sectional area of the weld (Figure 5, *a*).

Macrostructure of welded joints of V1341T alloy was studied on transverse sections, which were cut out of the weld central part. In order to reveal their features, chemical etching was performed in a solution, which consists of three acids: 72 ml HCl + 24 ml HNO_3 + 4 ml HF. Metallographic analysis of welded joint macrostructure showed that, irrespective of chemical composition of the used wire grades, all the welds are characterized by fine-grained uniform structure and absence of coarse defects (Figure 5, *c*–*e*). In the joint zone near the weld, areas with different degree of etching are observed, that reflects the impact of gradient conditions of the thermal cycle of welding on the morphology of structural transformations in the metal.

Conclusions

1. It is found that under the conditions of manual nonconsumable electrode argon-arc welding, aluminium alloy V1341T is characterized by a high susceptibility to hot cracking. The value of metal hot brittleness is A = 65.8–85.5 %. Application of filler wires lowers the hot cracking susceptibility of the alloy. In welding with batch-produced wires of ZvAMg63, ZV1201, Zv1217 grades, the hot brittleness value is A = 30.3–53.9 %, and when wire of ZvAK5 grade is used, this value for welds is equal to A = 6.6–19.8 %.

Application of manual nonconsumable electrode argon-arc welding of sheet aluminium alloy V1341T allows producing tight sound joints of this material with strength factor equal to 0.80–0.84 of base metal level, depending on chemical composition of filler wire grade. X-Ray inspection of the joints showed the absence of coarse defects in welds. At visual analysis of their face surface without the technological reinforcement, scattered pores of up to 0.08 mm size are observed that is 6 times lower than the admissible norms. Distance between the fine pores is 11.0–15.0 mm. Total extent of the fine pore line is equal to 7–8 mm on a 100 mm long section of the weld.

3. It is found that the average value of ultimate strength of the alloy welded joints, using different filler wire grades is σ_t = 199.9–209.0 MPa, and yield limit $\sigma_{0.2}$ = 136.6–147.6 MPa, relative elongation δ = = 4.0–5.2 %, bend angle α = 40–65 deg. Samples of the alloy welded joints fail in the base metal in the HAZ at the distance of 3–5 mm from the fusion line, irrespective of chemical composition of applied filler wires. Such a nature of fracture in this zone is due to the alloy sensitivity to technological heating, as a result of alloying component redistribution that lowers its strength.

4. Welded joints produced without filler wire application, are characterized by a lower level of mechanical properties: σ_t = 125.3–153.3 MPa, $\sigma_{0.2}$ = 110–144.6 MPa, δ = 0.7–1.4 %, α = 30–37 deg, compared to joints, produced with filler wires. Strength factor here is equal to 0.55. Proceeding from the obtained data, it should be noted that wire of ZvAK5 grade is the best one for reducing the hot cracking susceptibility of welds in manual welding of V1341T alloy, and if a complex of mechanical property values should be provided, this is Zv1217 wire. Nonconsumable electrode manual arc welding without filler is not allowed, when joining V1341T alloy.

1. Milman, Yu.V. (2008) *New high-strength aluminium alloys. Actual problems of modern materials science*. Vol. 1. Kiev, Akademperiodika, 597–612 [in Russian].
2. Ishchenko, A.Ya. (2008) Welding of aluminium alloys. *Inorganic materials science. Materials and technologies*. Vol. 2, Book 2. Kiev, Naukova Dumka, 238–253 [in Russian].
3. Yushchenko, K.A., Derlomenko, V.V. (2008) *Welding and weldability (joinability) of materials. Inorganic materials science. Materials and technologies*. Vol. 2, Book 2. Kiev, Naukova Dumka, 268–276 [in Russian].
4. Ishchenko, A.Ya., Labur, T.M. (2013) *Welding of modern structures of aluminium alloys*. Kiev, Naukova Dumka [in Russian].
5. Rabkin, D.M. (1986) *Metallurgy of fusion welding of aluminium and its alloys*. Kiev, Naukova Dumka [in Russian].
6. Lashko, N.F., Lashko-Avakyan, S.V. (1960) *Weldable light alloys*. Leningrad, Sudpromgiz [in Russian].
7. (2015) *DSTU EN ISO 10042:2015 (EN ISO 10042:2005, IDT; ISO 10042:2005, IDT)*: Welding — arc-welded joints in aluminium and its alloys. Quality levels for imperfections [in Ukrainian].

Received 11.12.2019

FEBRUARY 1, 1941 Production of Sherman tank began in the USA. Compared to riveted tank M-3, it had a larger caliber gun (75 mm), cast or welded turret. Pullman-Standard Company participated in fulfillment of the program on all-welded tank production. It developed the technology of welding the hull and turret. A conveyor line for hull assembly and welding was organized. Multilayer manual arc welding was performed in the downhand position, and after that the structure was installed into positioners. Automatic submerged-arc welding in equipment developed already in 1940, was used only for producing the heaviest part — tank wheels from low-carbon steel.