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# APPLICATION OF A-TIG WELDING FOR IMPROVING THE TECHNOLOGY OF MANUFACTURING AND REPAIR OF UNITS OF GAS TURBINE ENGINES AND INSTALLATIONS FROM TITANIUM ALLOYS

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**ABSTRACT**

The advantages of using the technology of A-TIG welding (TIG welding over the layer of activating flux–activator) of structurally complex elements of titanium alloys, including butt and spot overlapped joints of various thicknesses, as well as joints with variable heat removal, are shown. The relationship between the geometry of welds, structure and properties of welded joints produced by TIG and A-TIG welding methods were studied. A-TIG welding technology was tested in industrial conditions during creation and repair of problematic units of aircraft and convertible gas turbine engines. The A-TIG welding method is recommended for industrial implementation when creating welding structures from titanium alloys of a complex geometry.

**KEYWORDS:** TIG and A-TIG welding, activators, titanium alloys, butt and spot overlapped joints, variable heat removal, weld formation, structure and properties

## INTRODUCTION

Improving the quality, reliability and service life of welded structures, reducing weight and costs during their manufacture are constantly the focus of attention in industrial production. The need to solve these issues when creating complex highly-loaded and highly-critical units of aircraft gas turbine engines (GTE) is particularly relevant and even critical. The use of complex alloys and advanced manufacturing technologies does not always allow achieving ever growing requirements and indices. Therefore, the solution of problems is increasingly achieved by improving (with inevitable complication) of the design of GTE units, the creation of which by welding from individual elements in many cases is the most economical and technological way, probably even the only way. An example may be all-welded rotors, impellers, folded blades, etc. In view of the appearance and specifics of the material and designing features of GTE units, the search for technological, less time-consuming, waste-free method of their welding is quite relevant.

The aim of the work is to investigate the capabilities and to develop the technology of A-TIG welding of butt and spot overlapped joints of thin-sheet (thickness $\delta$ = 1.2–2.0 mm) VT-20 and OT-4-1 titanium alloys.

This work uses the results of studying the mechanism of welded metal penetration, and progressive approaches towards improvement of the welding technology, based on these results. One of these approaches is the use of A-TIG welding (TIG welding over the activating flux–activator) in manufacturing structures of steels [1–6], nickel [7] and titanium alloys [8–15]. The main positive effects of using activators in A-TIG welding of all the mentioned materials, as compared to the conventional TIG welding, are manifested in an increase in the penetrating capacity of the process (deep penetration), reducing the input energy, decrease in the length of HAZ, as well as the absence of pores in welds (Figures 1 and 2). During A-TIG welding of titanium alloys, this is mainly predetermined by the constriction of the welding arc by the products of thermal dissociation of the melting activator components [8, 10, 11, 15]. At the same time, the kinetics of melting also changes, the width is significantly reduced, the geometry and the shape of the weld penetration is changed. In the case of the constant speed of welding, the use of the activator in A-TIG welding allows 1.5–2.0 times reduction in the value of welding current without changing (with preservation) penetration (Figure 3), and, therefore, overheating of the welded metal, welding voltage and deformations are decreased.

The following variants and benefits of industrial use of the A-TIG welding method in the manufacture of units of gas turbine engines and installations are considered:

a) for butt joints in welding units with uneven heat removal from the place of welding:

- stability of weld formation increases by several times;
- it becomes possible to produce high-quality welds of structures, the thickness of whose joining elements differs by 2–3 times.

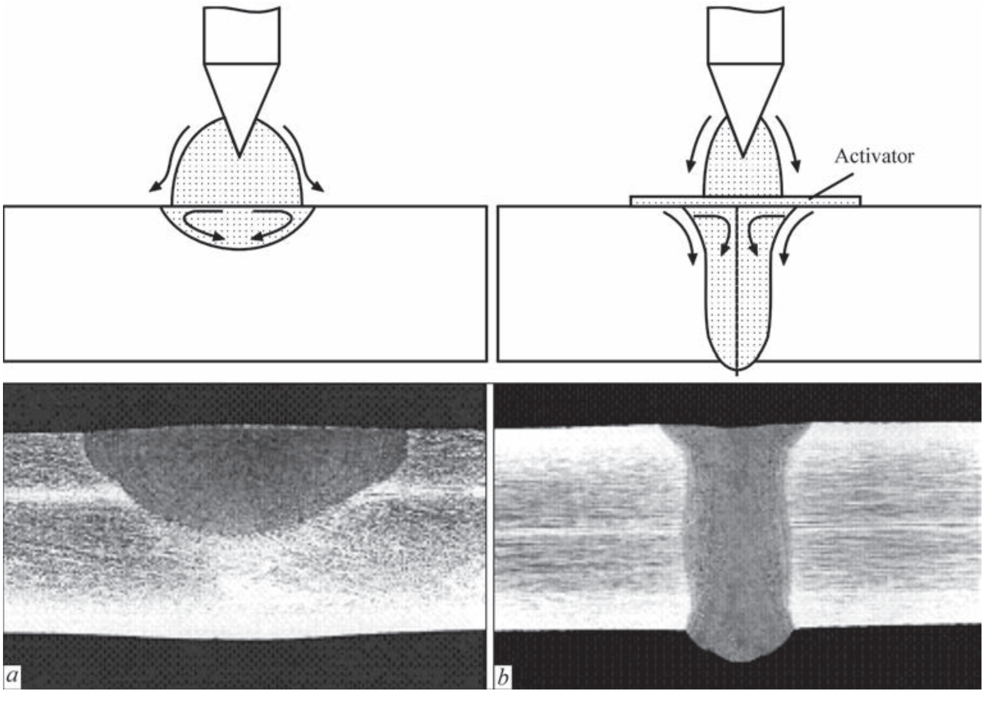


**Figure 1.** Schematic image and appearance of welds of stainless steel 04Kh18N10T of δ = 6 mm thick, produced by TIG (*a*) and A-TIG (*b*) welding on processes one welding mode: welding current is 200 A; speed of welding is 120 mm/min, arc length is 1.5 mm [1]

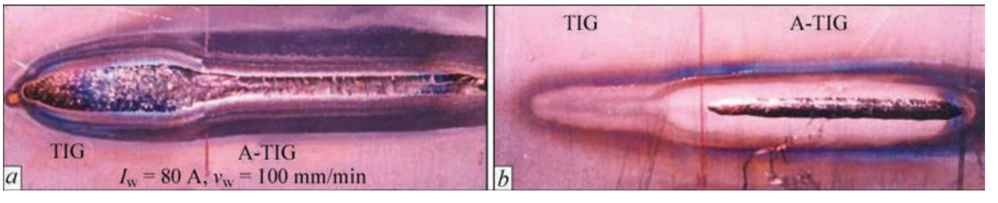


**Figure 2.** Appearance of welds, produced by TIG (left) and A-TIG (right) welding of VT-20 titanium alloy of δ = 3 mm thick on one welding mode: welding current is 80 A; speed of welding is 100 mm/min: *a* — outer weld surface; *b* — back surface (root) of the weld (results of personal investigations)

b) for overlapped joints:

● drilling of welded elements at the place of joining becomes unnecessary;

● the possibility of producing high-quality welded spots at a gap between the joining elements to 0.5 of the thickness (*H*) of welded metals, and with the use of filler material — to 1.0 N is provided*;*

A-TIG welding technology can be successfully applied to welding parts of variable cross-section, T- and different thickness joint units. Especially, it is effectively used in welding of high-precision, complex-loaded units and parts of engines and installations from structurally sensitive heat-resistant alloys based on iron, nickel and titanium.

## RESEARCH METHODS AND MATERIALS

The main task of the industrial introduction of a new A-TIG welding method consists in adaptation of the proposed methods and realization of their advantages with respect of specific conditions, equipment, units and alloys. The types of welded joints were determined by TS on a product.

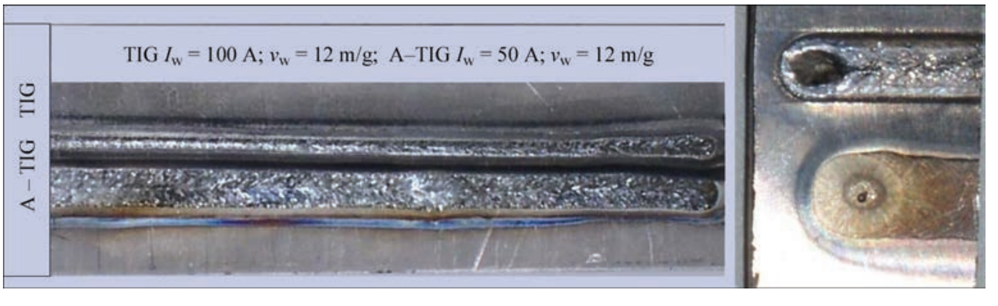


**Figure 3.** Appearance of weld surface at a full penetration, produced by TIG and A-TIG welding of VT-20 titanium alloy of δ = 2 mm thick at the same speed of welding of 200 mm/min: above — A-TIG, welding current is 50 A; below is TIG weld, welding current is 100 A (results of personal investigations)

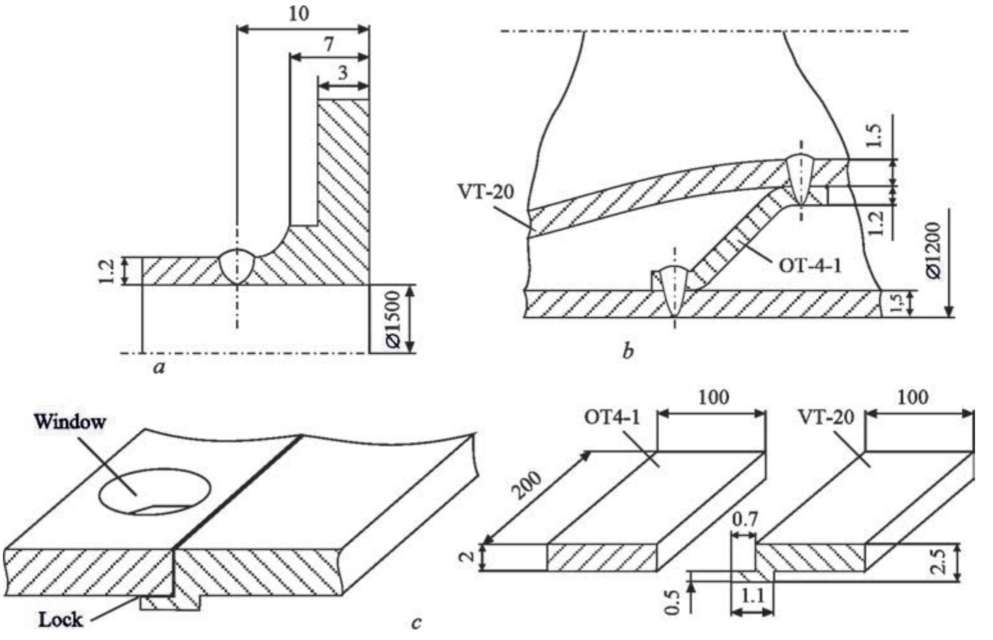


**Figure 4.** Schemes of fragments of welded units: frame ring-flange (non-symmetric heat removal), butt joint of OT-4 alloy (*a*); frame ring with overlapped spot joints of OT-4 and VT-20 alloys (*b*); frame ring with window, butt lock joint of OT-4 and VT-20 alloys (sketch (left) and elements (right) of welded joint) (*c*)

The structural design represents butt (Figure 4, *a*, *c*) and overlapped spot (Figure 4, *b*) joints. The material is VT-20 and OT-4-1 titanium alloys. The dimensions of units and products are: diameter is 1200–1500 mm, thickness is $\delta = 1.2$; 1.5 and 2.0 mm. Most of the experiments were carried out on flat specimens: butt joints, VT-20 alloy, dimensions of specimens are 150×150×2 mm, 220×80×2 mm and 220×50×1.2 mm; spot overlapped joints, VT-20 and OT-4-1 alloys in a dissimilar combination, dimensions of specimens are 100×60 mm, thickness is 2 + 2 mm, 1.5 + 1.5 mm and 1.5 + 1.2 mm.

Requirements for welds design:

● butt welds: geometry and dimensions of welds are in accordance with GOST 1474–76;

● spot welds: geometry and dimensions of welds are in accordance with GOST 14776–79 (14778–76), diameter of a spot on the facial side of the weld is 6–10 mm, the root is 5–7 mm, the reinforcement (weakening) of the weld is (±0.2 mm).

The mechanical and service characteristics of welded joints should be not lower than 0.9 from the properties of the base metal. The limitations on the deformations of welded joints and stresses in them are specified in the process of mastering edge preparation on specific units, taking into account the existing equipment and a subsequent heat treatment.

The methods, scope and standards of the welds testing are: external inspection is 100 %.

The presence and dimensions of undercuts, cracks on the surface and the presence of splashes are checked. X-ray testing is 100 % of welds. The presence of lacks of penetration, lacks of fusion, cracks, pores and cavities inside the weld is determined.

The preparation, in addition to the fulfillment of the listed technical conditions, had to provide:

● for butt joints: elimination of lacks of fusion, displacement of fusion from the joint; prevention of penetrations caused by nonuniform heat removal; increasing the stability of weld formation;

● for overlapped joints: elimination of the need for drilling before welding; producing high-quality spot joints at increased gaps.

The type of welding equipment, its parameters, welding modes and conditions were selected based on the conditions necessary to obtain high-quality weld formation on the metal of the appropriate thickness and grade, as well as taking into account the equipment and technologies used in production. As a power source for the welding arc, VSVU-315 rectifier was used. Spot overlapped welded joints were produced in the chambers “Atmosfera-6m” and Ob-427 with a controlled shielding atmosphere. The use of such chambers is caused by the need in reliable and stable protection of the welding pool and heat-affected zone from the harmful effect of air, especially in the place where one sheet element overlaps another. Moreover, in such chambers a continuous monitoring of the composition of the shielding atmosphere is possible. The welding of specimens to determine the effect of heat removal was performed in a welding table with a sampling along the joint of 5×10 mm and with clamping of the plates to be welded at a distance of 10 mm from the joint line. For protection against oxidation during welding outside the chamber, inert gas blow-

**Table 1.** Welding modes and characteristics of butt welds from VT-20 alloy of d = 2 mm thick

| Number | Welding method | Welding current $I_w$, A | Welding speed $v_w$, mm/min | Weld width $B$ — surface/$c$ — root, mm | Deviation of weld axis from joint line, mm | | Deflection along the axis Δ, mm |
|---|---|---|---|---|---|---|---|
| | | | | | Average | Surges* | |
| 1 | TIG | 85 | 170 | 8.0–8.2<br>4.0–4.8 | 0.3<br>0.5 | 0.6<br>1.2 | 12.8 |
| 2 | A-TIG | 80 | 340 | 3.4–3.5<br>2.8–3.4 | 0.3<br>0.4 | 0.4<br>0.8 | 7.1 |

ing was used, through sampling in the table from the root part and “boots” of 50 mm long and 20 mm wide from the weld surface. For welding, the following were used: a standard TIG welding torch with a nozzle of 16 mm diameter, the consumption of shielding gas (argon) in the nozzle — 7–8 l/min, in the “boot” — 4–5 l/min, for blowing 5–6 l/min; welding electrode with a diameter of 2.1 mm of WT20 grade (made of W — 2 % $ThO_2$ alloy). To carry out welding experiments, oxygen-free halide activator PATIG-T was used. The welding modes (Table 1) were selected based on the need to provide a stable, high-quality penetration of the specimens to be welded.

The activator in the form of a paste was applied with a brush in a thin, uniform layer on the facial surface of a part to be welded. Its width was 8–10 mm on each side from the welded joint or on a diameter of ≈20 mm at the place of making spot in the case of overlapped joining. The thickness of the activator layer was determined based on the need of obtaining the required penetration depth and process stability. At the same time, it was taken into account that for certain ranges of welding current values, there is an optimal thickness of the activator layer, at which the maximum penetration depth with high-quality weld formation is achieved. An excessive thickness of the activator layer, especially at the butt joints, leads to undesirable results — violation of process stability, slagging of the tungsten electrode.

As was already mentioned, in production conditions welded joints of poor quality are often produced as far as it is necessary to change heat input and heat removal along the joint length due to wear of technological assembly and welding equipment, unsuccessful structure of a welded joint, inaccurate manufacture of units to be welded, inaccurate guiding of the arc along the joint, etc. Taking into account the fact that the presence of an activator changes the nature of heat input and penetration of the metal to be welded, which, as a result, stabilizes the process of weld formation, the experiments were conducted to determine the influence of using activators on reduction of the abovementioned negative factors.

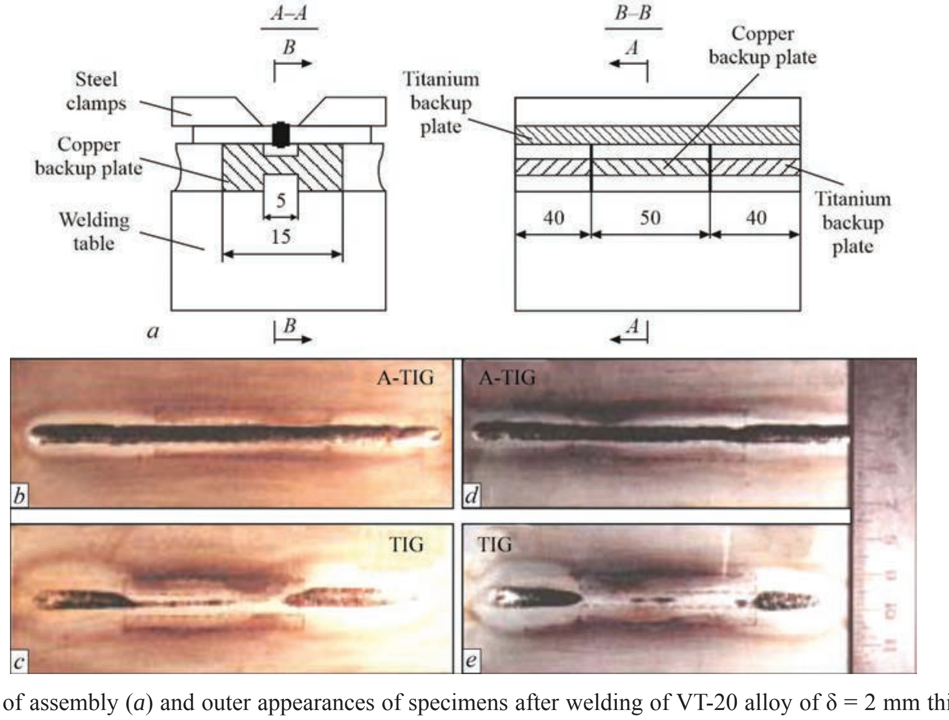


**Figure 5.** Scheme of assembly (*a*) and outer appearances of specimens after welding of VT-20 alloy of δ = 2 mm thick at a full penetration on the side of the weld root with heat removal, which changes along the length of the specimen: A-TIG welding (*b*, *d*); TIG welding (*c*, *d*); with lower heat removal (*b*, *c*); with greater heat removal (*d*, *e*). The dotted line in Figure 5, *b*–*e* marks the location of copper backup plate

**Table 2.** Welding modes and results of the stability of weld formation of butt joints from VT-20 alloy of δ = 2 mm thick at a variable heat removal (see Figure 5)

| Specimen number | Welding conditions | Arc voltage $U_a$, V | $I_w$, A | $v_w$, mm/min | Weld width, mm surface/root | Changing the weld width surface/root | Note |
|---|---|---|---|---|---|---|---|
| TIG welding | | | | | | | |
| 1–1 | Without heat removal | 8.2–8.4 | 65 | | 9.0–8.6/5.3–5.7 | – | – |
| 1–2 | Ti–Cu–Ti with heat removal, distance — 2 mm | –»– | –»– | 100 | 7.8–7.2/0–1.2 | 1.2–1.4/5.3–4.5 | Figure 5, *e* |
| 1–3 | Ti–Cu–Ti with heat removal, distance — 3 mm | –»– | –»– | | 7.5–7.6/0–1.3 | 1.5–1.0/5.3–4.4 | Figure 5, *c* |
| A-TIG welding | | | | | | | |
| 2–1 | Without heat removal | 8.2–8.4 | 40 | | 2.8/5.5–5.4 | – | – |
| 2–2 | Ti–Cu–Ti with heat removal, distance — 2 mm | –»– | –»– | 100 | 2.6/5.0–4.9 | 0.2/0.5 | Figure 5, *d* |
| 2–3 | Ti–Cu–Ti with heat removal, distance — 3 mm | –»– | –»– | | 2.6/5.1 | 0.2/0.4–0.3 | Figure 5, *b* |

A variable heat removal was created by using assembly backup plates along the length of the specimen, having strongly different thermal conductivity and heat capacity of the materials: titanium-copper-titanium (Figure 5, *a*). The welding modes and conditions were chosen similarly to those described earlier. The speed of welding was slightly reduced (to 100 mm/min), and the current was increased (up to 65 and 45 A in welding at different heat removal) to enhance the impact of heat removal. In addition, to change the conditions of heat removal, heat removing tacks were placed at different (2 and 3 mm) distance from the weld axis. Welding modes and research results are summarized in Table 2 and Figure 5.

In production conditions, when assembling overlapped joints of frame rings of large diameters, often gaps appear between them, which leads to considerable difficulties in producing high-quality joints. Moreover, to carry out the fusion according to the technological process, the upper sheet is drilled, and then the gap is filled by TIG welding in the chamber, which significantly increases the labor, metal and energy consumption of production.

Considering a significant increase in the penetrating capacity of the arc and reducing the overheating of welded metal during A-TIG welding, the experiments were conducted to find out the possibility of eliminating the mentioned difficulties and drawbacks. The main studies were performed in the the plates from VT-20 alloy with 2 mm thickness, as well as of OT-4 alloy with 1 mm thickness, overlapped each other. The testing experiments were performed on the

**Table 3.** Welding modes and results of studying during welding of specimen-imitator – frame ring with windows from VT-20 alloy of δ = 2 mm thick (see Figure 6)

| Specimen number | Welding conditions Type of joint | $U_a$, V | $I_w$, A | $v_w$, mm/min | Weld width, mm surface/root | Note |
|---|---|---|---|---|---|---|
| TIG welding | | | | | | |
| 1 | Plate, 2 welds nearby | 8 | 100 | 200 | 7.5–7.9/3.2–4.6 | Figure 3 below |
| | | A-TIG welding | | | | |
| 2 | | 10.5 | 50 | 200 | 2.2–3.2/2.4–3.2 | Figure 3 above |
| A-TIG welding | | | | | | |
| 1 | Butt with a “window” | 10.5 | 60 | 200 | 3.5–3.6/4.3–4.7 | Figure 6, *d* |
| | | A-TIG welding | | | | |
| 2 | | 10.5 | 50 | 200 | 3.6–3.7/4.0–4.1 | Figure 7, *b* |
| TIG welding | | | | | | |
| 1 | Butt with a “window” | 8 | 100 | 200 | 7.6/3.8 | Figures 6, *b*,7, *a* |
| | | TIG welding | | | | |
| 2 | | 8 | 110 | 12 | 8.5/6.0 | Figure 6, *c* |

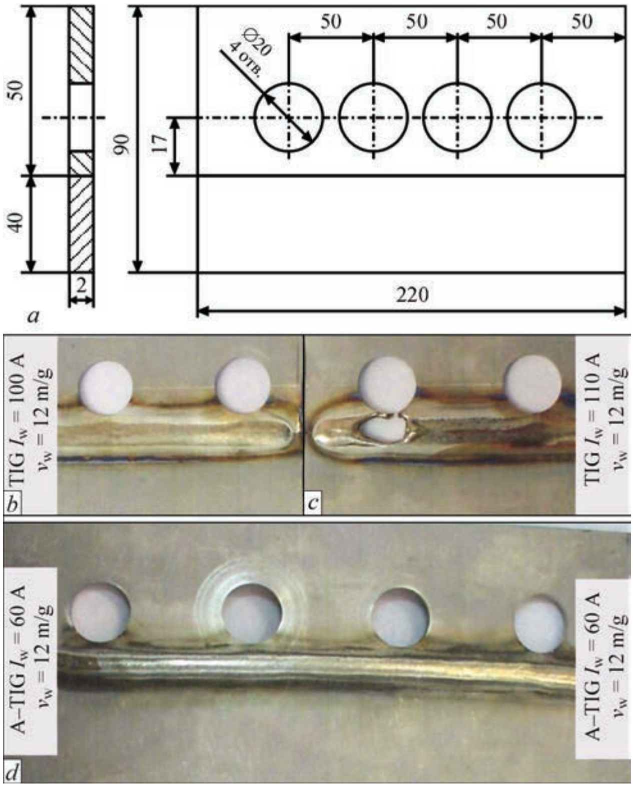


**Figure 6.** Appearance of fragments of welded specimens-imitators from VT-20 alloy of δ = 2 mm thick at a full penetration: scheme of preparation of specimen-imitator (*a*); TIG welding, welding current is 100 A (*b*) and 110 A (*c*); A-TIG welding, welding current is 60 A (*d*)

specimens that simulate real welded joints: the plate from VT-20 alloy of 1.5 mm thickness overlapped the plate of OT-4-1 alloy of 1.2 mm thickness and vice versa. The gaps between the plates were set by foil strips of 0.2; 0,5; 0.8 and 1 mm thickness between the plates. The specimens were assembled by tacks on the corners of the plates. The current and time of welding were selected from the condition of obtaining a full penetration of the lower sheet with the minimum possible diameter of the spot and upsetting of the metal. Other welding conditions are the same as while producing butt joints.

## RESEARCH RESULTS

Analysis of the obtained results allows making a conclusion that in general when applying A-TIG welding of butt joints:

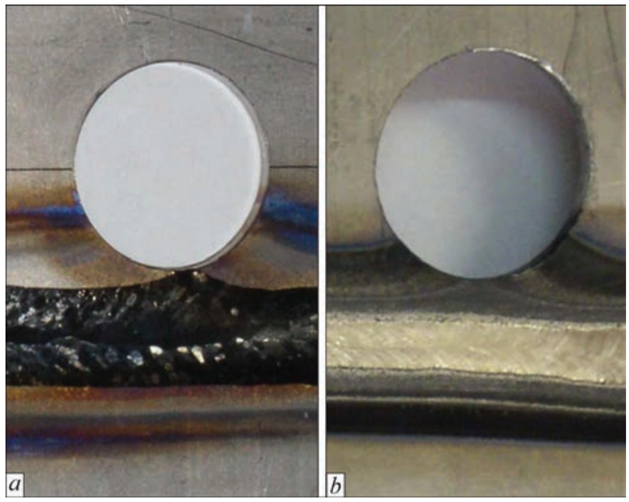


**Figure 7.** Appearance of fragments of welded specimens-imitators from VT-20 alloy of δ = 2 mm thick at a full penetration: *a* — TIG welding, welding current is 100 A; *b* — A-TIG welding, welding current is 50 A

- the width of the weld is reduced by 2–3 times at a simultaneous decrease in welding current by 30–50 %;
- the impact of heat removal is reduced judging from the width of the weld from its surface by 5–7 times, and by 9–12 times from the root of the weld.

The similar results were obtained in welding of butt joints of the specimen-imitator (δ = 2 mm thick) from VT-20 alloy — the frame rings with windows. Welding modes and research results are summarized in Table 3 and in Figures 6, 7. Application of A-TIG welding allows avoiding partial melting of metal at the window place.

Analysis of the results of metalographic examinations shows that the positive effect of the activator is manifested in reduction of the weld width, a significant reduction in HAZ (Figure 8), as well as in refinement of both primary β-grains and α- and α′-plates (Figure 9).

The positive effect of using the activator in A-TIG welding of butt joints when changing the heat removal along the length of the specimen is clearly seen as compared to Figure 5, *b*, *d* and 5, *c*, *e*. A-TIG weld is stable across the width along the entire length of the specimen, and in TIG of the weld, penetration in the place of the backup plate disappears.

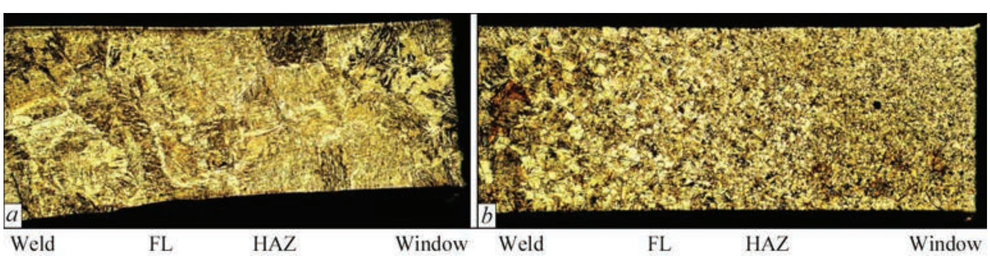


**Figure 8.** Macrostructure (×25) of welded joints of VT-20 titanium alloy: *a* — TIG welding; *b* — A-TIG welding, FL — fusion line, HAZ — heat-affected zone

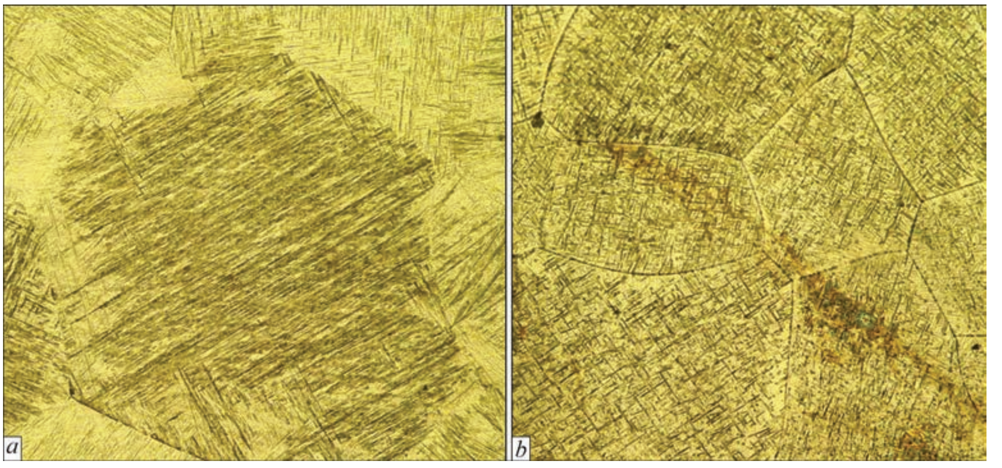


**Figure 9.** Microstructure (×100) of weld metal (VT-20 alloy): *a* — TIG weld; *b* — A-TIG weld

From the results of the experiments presented in Tables 4, 5, it is seen, that even during assembly, overlapped joints can not be produced without a gap if a welded spot activator with the penetration of the lower sheet is not used — spots of a large diameter without through penetration are formed. A significant increase in the current or time of welding leads to an excessive increase in the diameter of the spot and the burnthrough of both sheets.

The use of A-TIG welding at lower current values allows producing a through penetration at small (within TS) diameters of spots (Tables 4, 5; Figures 10–12) and while complying with all the requirements to similar joints. An increase in the gap causes the need to

**Table 4.** Welding modes and characteristics of spot overlapped welds on specimens from VT20 (δ = 2 + 2 mm) and OT-4 (δ = 1 + 1 mm), without a gap

| Specimen number | Welding conditions | $I_w$, A | Time of welding $t_w$, s | Spot diameter, surface/root, mm | Note |
|---|---|---|---|---|---|
| 1-0 | VT20 (2+2 mm) A-TIG welding | 80 | 10 | 5.0/8.5 | Weakening of the weld 0.1 mm |
| | | | 5 | 5.0/5.0 | Weakening of the weld 0.2 mm |
| 2-0 | OT-4 (1+1 mm) TIG welding | 40 | 10 | 5.5/0 | Lack of penetration, weld reinforcement 0.2 mm |
| | | | 5 | 5.0/0 | Lack of penetration, weld reinforcement 0.1 mm |
| | A-TIG welding | | 10 | 6.0/6.5 | Weakening of the weld 0.2 mm |
| | | | 5 | 3.6/2.5 | Weakening of the weld 0.1 mm |

**Table 5.** Welding modes and characteristics of spot overlapped welds on specimens from VT20, δ = 1.5 mm + OT-4-1, δ = 1.2 mm with different gaps

| Specimen number | Welding conditions (gap between the plates to be welded, mm) | $I_w$, A | $t_w$, s | Spot diameter, surface/root, mm | Note |
|---|---|---|---|---|---|
| TIG welding | | | | | |
| 1–1 | Without a gap | 50 | 4 | 7.5/0 | Lack of penetration |
| 1–2 | | 50 | 10 | 11/0 | |
| 1–3 | | 75 | 5 | 9.5/0 | |
| A-TIG welding | | | | | |
| 1–4 | Without a gap | 40 | 4 | 4.1/2.6 | – |
| 1–5 | | 50 | 4 | 4.1/6.0 | Weakening, 0.2 mm |
| TIG welding | | | | | |
| 2–1 | 0.25 | 70 | 4 | 12.0/0 | Lack of penetration |
| A-TIG welding | | | | | |
| 2–2 | 0.25 | 50 | 3 | 4.0/5.2 | – |
| 3–1 | 0.5 | 45 | 6 | 5.8/5.8 | Weakening, 0.3 mm |
| 3–2 | | 60 | 6 | 8.2/6.2 | Weakening, 0.4 mm |
| 4–1 | 1.0 | 50 | 4 | 7.5/0 | Lack of penetration |
| 4–2 | | 60 | 5 | 6.0/4.7 | Weakening, 0.8 mm |
| 4–3 | | 60 | 6 | 8.0/8.5 | Weakening, 0.1 mm |

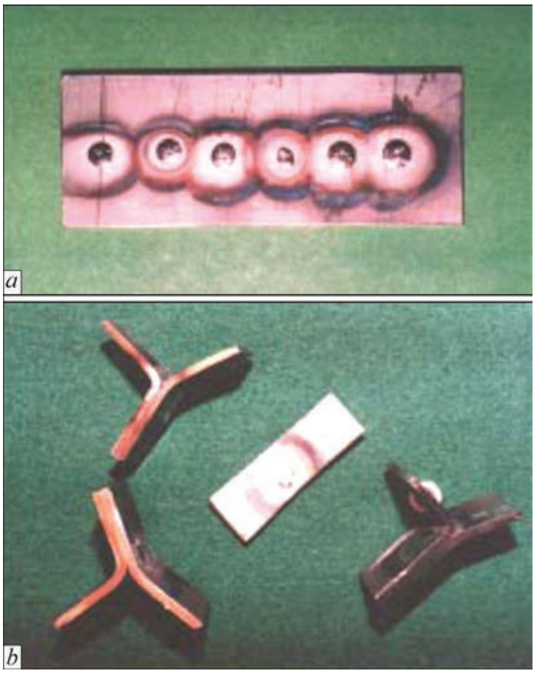

**Figure 10.** Appearance of spot overlapped welded joints from VT-20 alloy of δ = 2 + 2 mm thick: back side of the joint (weld root) (*a*); specimens after bending test (*b*)

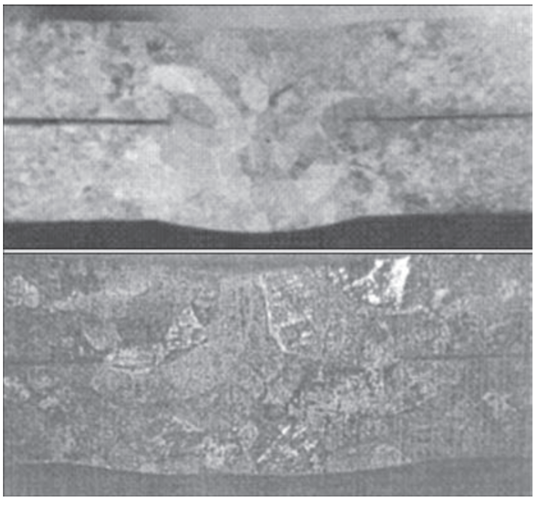

**Figure 11.** Macrostructures of cross-sections of spot overlapped welded joints from VT-20 alloy of δ = 2 + 2 mm thick, produced by A-TIG welding without a gap

increase current and welding time, use filler material, since at the gaps more than 0.5 mm, weakening of the weld exceeds the admissible (0.2–0.3 mm) values. It should be noted that a significant increase in welding current leads to an excessive increase in the diameter and to the weakening of the weld in its root part, and an increase in welding time leads to the corresponding change in the facial part of the weld (Figure 12).

The mechanical properties of the butt joints were evaluated by the toughness, since this characteristic is more sensitive to technological and other factors

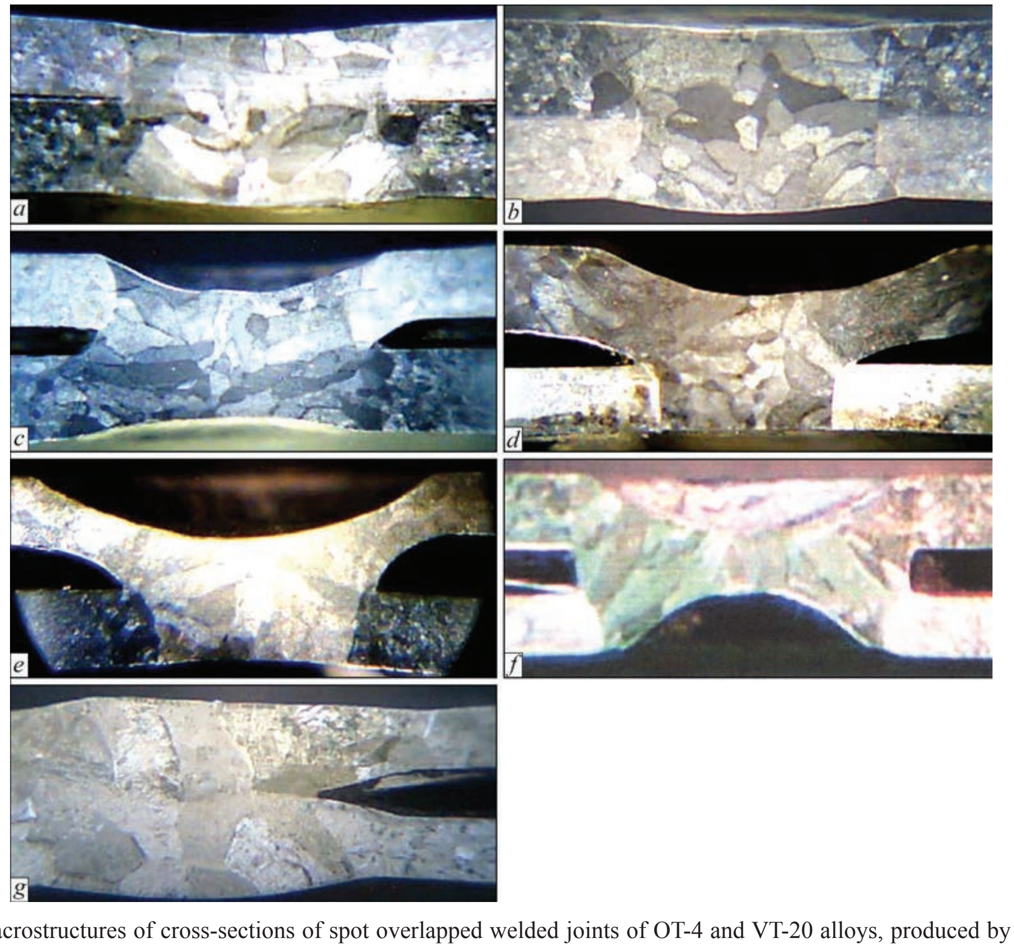

**Figure 12.** Macrostructures of cross-sections of spot overlapped welded joints of OT-4 and VT-20 alloys, produced by A-TIG welding: without a gap (*a*, *b*); gap is 0.5 mm (*c*, *d*); gap is 1.2 mm (*e*, *f*, *g*); above is OT-4 alloy, δ = 1.2 mm (*a*, *c*, *d*); above is VT-20 alloy, δ = 1.5 mm (*b*, *d*, *f*); OT-4 alloy, δ = 1.2 mm (with filler) (*g*)

**Table 6.** Mechanical properties of butt welded joints from VT-20 alloy (δ = 2 mm)

| Number | Area of welded joint | Impact toughness, J/cm$^2$ | Discrepancy of values, % |
|---|---|---|---|
| 1 | Base metal | 54.0–59.5/57.2 | 10 |
| TIG welding | | | |
| 2 | HAZ | 68.7–77.4/72.7 | 12.5 |
| | FL – Weld | 62.9–71.3/66.75 | 13.5 |
| | Weld | 69.9–87.5/78.5 | 25.0 |
| A-TIG welding | | | |
| 3 | FL – Weld | 57.9–63.3/61.0 | 9.2 |
| | Weld | 68.9–73.4/71.0 | 6.5 |

**Table 7.** Properties of spot overlapped welded joints from VT-20 alloy (δ = 2 + 2 mm), produced by A-TIG welding

| Number | Assembly quality | Fracture force *P*, kgf | Shear strength $\tau_{av}^{*}$, MPa | Diameter of welded spot in the place of fracture, mm | Angle of bending (tests on impact bending), deg |
|---|---|---|---|---|---|
| 1 | Without a gap | 1022.0 | 507 | 4.6 | 85 |
| | | 1133.2 | 602 | 5.2 | 96 |
| 2 | Gap is 1 mm | 17289 | 467 | 6.8 | 98 |
| | | 1558.6 | 541 | 5.9 | 95 |

*The expression is conditional, during fracture a tear-out of spot occurs, not a shear.

and more demonstrative than, let us say, the tensile strength. The flat specimens of type MI-49 GOST 9454–78 of 2 mm thickness with a round notch, made in different areas of the welded joint were tested.

From the results presented in Table 6, it can be concluded that the use of activators in most cases slightly changes the properties of the welded metal.

It should be noted that additional low-temperature annealing (650 °C, 30 min) leads to equalization of properties to the values of the base metal.

The properties of the spot overlappled welded joints were evaluated both by the results of the shear tests of the specimens MI-25 (2 + 2 mm) of type XX according to GOST 6996–66 and technological test on impact bending. The test results are presented in Table 7. The fracture occurs on the base metal (in some cases — across HAZ) at the values of loading and bending angles larger than those caused by TS on products and specified by GOST.

## CONCLUSIONS

1. The positive effect of using A-TIG welding of thin-sheet (1–2 mm) titanium alloys consists in reducing dimensions of the weld and HAZ, lower overheating of welded metal and, as a consequence, some decrease in welding stresses and strains, reduction in sensitivity to nonuniform heat removal from the welding zone and different thickness of elements to be welded.

2. Applying A-TIG welding method to produce spot overlapped joints allows providing high-quality joints without drilling the upper element of the welded joint at reduced welding currents, and using TIG welding, such joints can not be produced. In addition, performing A-TIG welding, it becomes possible to produce joints with violations of assembly, i.e. with gaps between the sheets to be welded, which can reach the thickness of the upper element.

3.The results of the perfromed studies allow recommending the A-TIG welding method using the proposed PATIG-T activator in creating complex geometry structures of titanium alloys of small thicknesses.

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**CONFLICT OF INTEREST**

The Authors declare no conflict of interest

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