Vrzhyzhevskyi E. L.[1], *Piskun N. V.*[1], *Taranova T. G.*[1], *Akhonin S. V.*[1], *Statkevich I. I.*[1], *Bogajchuk I. L.*[1], *Zvorykin C. O.*[2]

[1] **E. O. Paton Electric Welding Institute of NAS of Ukraine. Kiev, Ukraine**
[2] **Ukrainian Research Institute of Aviation Technology, JSC. Kiev, Ukraine**

PREVENTION OF COLD CRACKS FORMATION DURING ELECTRON-BEAM WELDING OF ALLOY BASED ON TiAl SYSTEM INTERMETALLIC COMPOUND

Reasons of cold cracks formation in welded joints of 10 mm thickness plates from titan aluminide of TiAl system during electron-beam welding were analyzed. It was found that in order to protect the transversal cold cracks formation in welded joints of titan aluminide samples during electron-beam welding realization it is necessary to fulfill local thermal treatment (LTT) preliminary heating with subsequent thermal treatment. Investigations of thermal processes during electron-beam welding, as well as structure of welded joints, permits to develop such welding technology, which practically eliminate cracking formation in welded joints. Welding conditions were developed which beside the cracks formation prevention permits to obtain the welding seam strength, which is better the strength of basic material. [dx.doi.org/10.29010/86.6]

Keywords: *titan aluminide; cold cracks; electron-beam welding; preliminary heating and local thermal treatment; beam scanning; microstructure; fractographic investigations.*

Introduction

The interest in alloys based on TiAl system titan intermetallic compounds is due to its application prospectivity in constructions of gas-turbine engines and other items of aerospace equipment.

TiAl-based titan aluminide is one of the most valuable materials owing to its low density and high strength which increases at the expense of high oxidation resistance and creep deformation. Nevertheless, low plasticity of these alloys at the room temperature complicates the technological treatment and thereby limits its industrial application. Utilization of titan aluminide in various purposes constructions depends on creation of effective methods of its treatment, including welding. The electron-beam welding (EBW) is one of most reliable method of high quality joint realization.

Problem statement

Due to low plasticity the titan aluminides are sensible to the stresses arisen under conditions of non-uniform heating during the welding and are inclined to initiation of cold transversal cracks in welded joints. In order to eliminate its formation the preliminary heating of samples was carried out according to [1]. Such method permits to reduce the temperature gradient during the welding and thereby reduce the velocity of transient stresses increase. Utilization of local annealing of welded joints at the temperature 900 °C by the electron beam immediately in the chamber reduces the residual stresses by several times. The ingots were obtained by electron-beam welding method with intermediate vessel utilization. Investigations were obtained with samples of titan aluminide γ-alloy of the following compositions (mass %): Ti-45.92 %; Al-44.54 %; Nb-5.26 %; Cr-2.82 %; Zr-3.16 %.

Titan aluminides are sensitive highly to the stresses which are formed under conditions of non-uniform heating during the welding and, consequently, are inclined to initiation of cold transversal cracks in welded joints [1]. As it shown in [2], for high-quality welded joint obtaining such conditions should be provided, which ensures slow velocity of the plates cooling that promotes more plastic structure of welded joints. In order to avoid the transversal cracks formation in the welded joints during electron-beam welding it is recommended by authors of [3] to use preliminary heating of the samples subjected to welding up to the temperature of 400—500 °C, which is carried out in the welding chamber. Nevertheless, these parameters are established for the given alloy only.

Material welding is important technological process during production of various purposes items. Nevertheless, during the electron-beam welding of TiAl intermetallic compound the inadmissible effect such as cold cracks, formed in the welded joint, is observed in several cases.

The goals of this article are the investigation of cracks formation causes in welded joints during welding of intermetallic compound on titan aluminide base. Further, on the base of investigations carried out, in is necessary to develop the method to avoid this phenomenon.

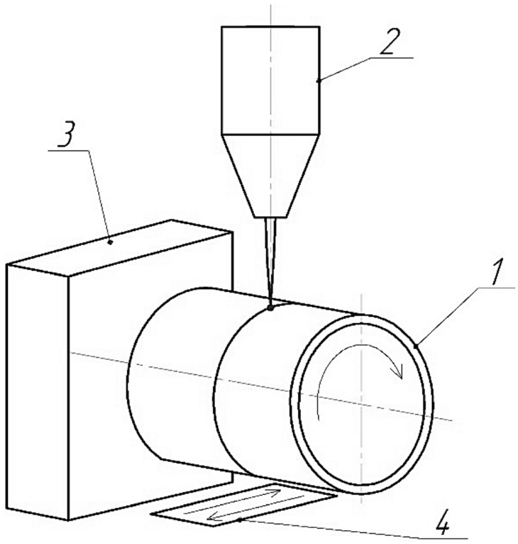


Fig. 1. Schematic view of bladed disks EBW process:
1 — bladed disks under welding; *2* — electron gun; *3* — rotator;
4 — projection of bladed disks rotational motion onto the plane level

Results of investigation

Investigation of thermal processes during electron-beam welding and structure of welded joints permits to develop such welding technology which in fact prevents the cracks formation in welded joints. Welding conditions are developed which besides of crack formation prevention permit also to obtain such welding seam strength which is better than the basic material strength.

Investigations of welded joints of TiAl system titan intermetallic compounds were carried out with the samples of 10 mm thickness which may be used for manufacturing of the bladed disks and blades of aircraft engine compressors.

Schematic view of bladed disks EBW process is in the Fig. 1

Works for technology development of electron-beam welding of intermetallic compound on titan aluminide base were carried out. In the Fig. 2 the schematic view of EBW process with local thermal treatment by electron-beam welding gun is presented. Preliminary heating and local thermal treatment were carried out by translation motion of gun with defocused beam swept by specially developed program. Such beam motion is a projection of circular rotation of bladed disks welded onto the plane (see Fig. 1).

Accessories for the sample fixing, as well as EBW technology, were developed. Blanks of investigated samples of 10 mm thickness were annealed preliminary in vacuum at the temperature 1,150 °C during 2 hours. Then EBW in vacuum by single-pass operation with

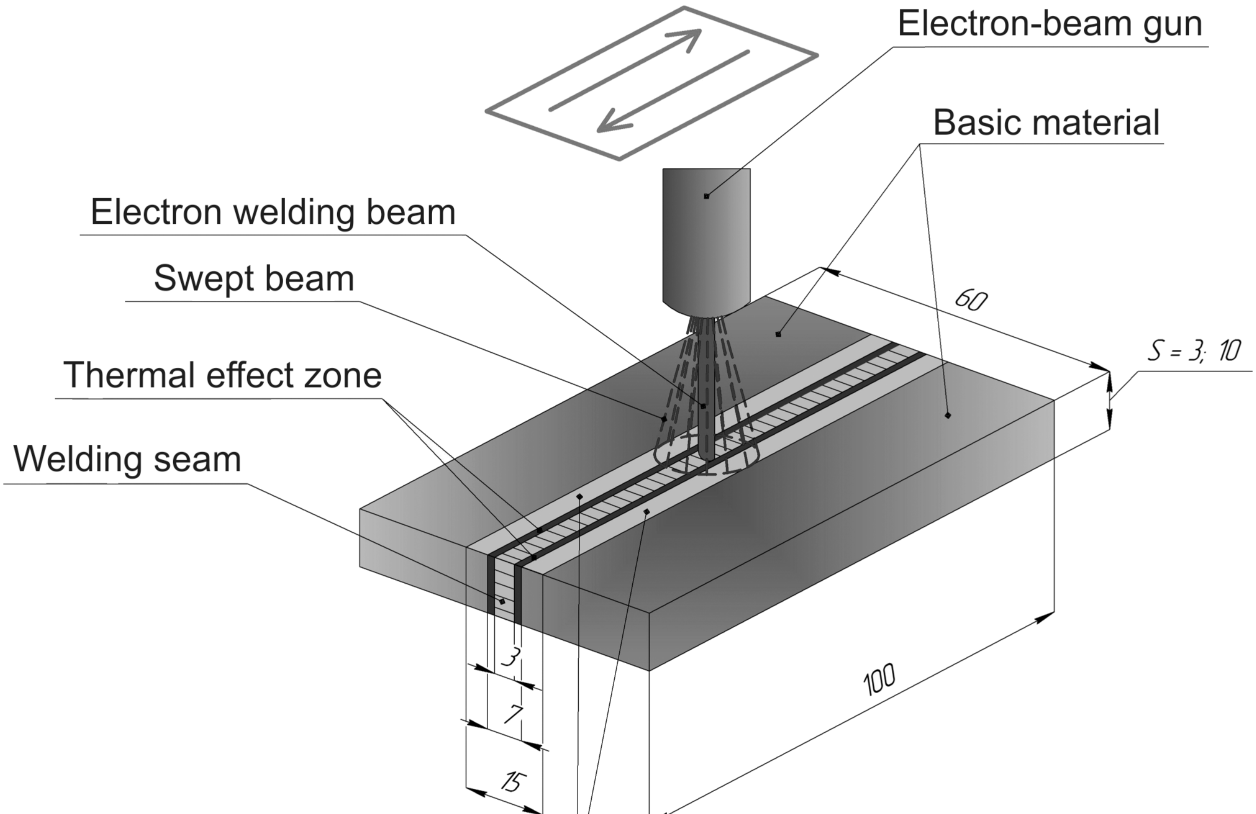


Fig. 2. General schematic view of EBW with local thermal treatment by movable electron-beam welding gun

the plates through penetration in lower position was carried out with УЛ-144 plant equipped with ЭЛА-60/60 power supply. Preliminary heating was carried out in the plates joint region only by several passing of beam at low heating power until the thermocouple at lower surface was indicate the heating up to required temperature (about 450 °C).

Conformably to the welding of 10 mm thickness plates of TiAl system intermetallic compound titan alloy, the authors were demonstrated earlier the effectivity of preliminary heating of the welding area [4], that permits to reduce the transient tensile stresses and obtain such microstructure, which ensures more plastic properties of seam metal.

Immediately after welding process completion for 10 mm thickness samples the annealing was carried out by means of beam scanning at the temperature 900 °C during 5 min. For the temperature checking the chromel-alumel thermocouple was used.

The welding was carried out with utilization of the following condition parameters: U_{acc} = 60 kV, I_{eb} = 100 mA, v_{weld} = 7 mm·s^{-1}, $P = 6.67 \cdot 10^{-3}$ Pa. The EBW was realized by using the transversal ellipsoidal scanning.

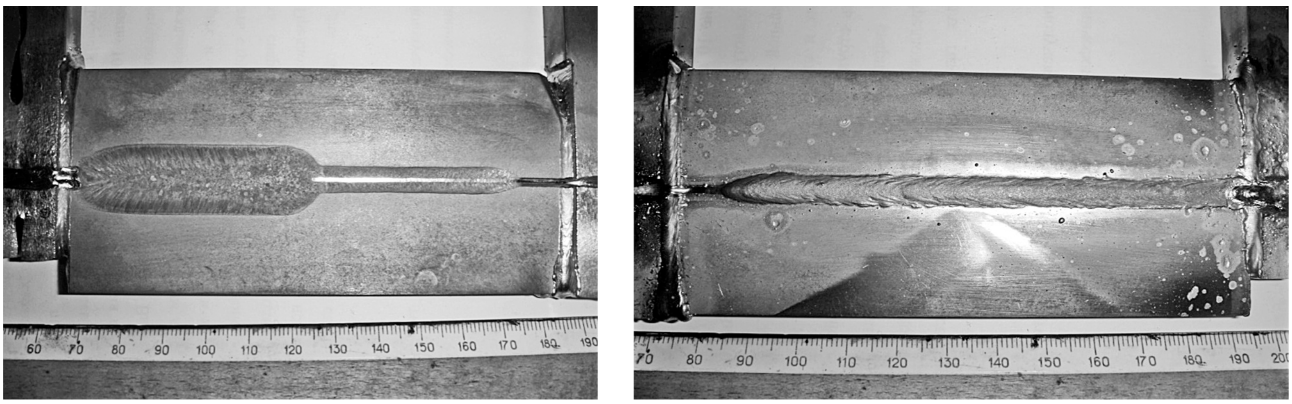
Optimal conditions of samples welding were determined. The welded joints were obtained with the attachment manufactured and with utilization of welding conditions developed (see Fig. 3, *a* and *b*). During the samples cooling the cold cracks appear in welded joints and for elimination of its appearance the sample welding with preliminary heating by electron beam was carried out. The heating temperature was changed from 200 °C to 500 °C. At that, the quantity of cracks, formed during the sample cooling, was calculated. It was revealed, that minimum quantity of cracks during EBW was observed when the preliminary heating from 400 °C to 500 °C was used. Nevertheless, total elimination of cracks origin is not succeeding. In result of the work carried out it was revealed that besides preliminary heating it is necessary to fulfill the local thermal treatment immediately after welding termination by means of the beam scanning along the seam and thermal influence zone. It permits to reduce the velocity of transient stresses increase during welding, as well as the level of residual welding stresses, which permits to avoid the cold cracks formation.

On the base of investigation results the technology of sheet workpieces electron-beam welding was developed, which permits to avoid the cracks in welded joints and improve its mechanical properties.

In Fig. 4 the microstructure of welded joint seam metal of 10 mm thickness sample is presented. Fig 4 clearly shows, that the microstructure is the large crystallites elongated along the heat sink (see Fig. 4, *a*). The seam metal has two-component ($\gamma + \alpha_2$) structure, in which α_2-phase released in form of fine-dispersed needle-shaped formations of martensite type α'-phase (see Fig. 4, *b*). According to the [2], along the crystal boundaries the well-ordered β_0 (β_2)-phase is formed. Seam metal hardness is high and is equal to HV3–5110, 5270, 5430 MPa. Obviously, it is connected with such fact that under thermal condition of welding the hardening taken place at the expense of fine-dispersed needle-shaped formations of martensite type α'-phase releasing

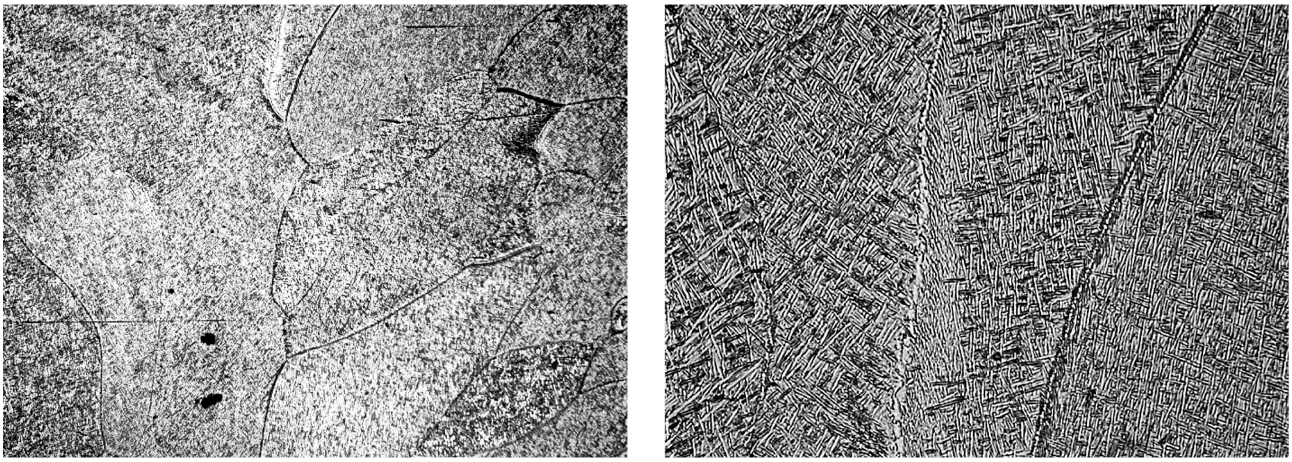
In Fig. 5 the microstructure of TAZ of samples investigated is presented. In this zone, bordering on basic metal, the clumps of ($\gamma + \alpha_2$)-phase is observed, which size is more than that in basic metal (see Fig. 4, *a*, *b*). Width of plates of α_2-phase in TAZ is 7.5—10 mm. These values are considerably higher than that for basic metal, which size is 2.5—5 mm.

During transition to TAZ the hardness reduction up to 4,810 MPa is observed. Hardness values in this area are intermediate values between the above-mentioned seam metal hardness and basic metal hardness. In basic metal the hardness is 3,570—3,850 MPa



a *b*

Fig. 3. External view of welded joint of 10 mm thickness plates from TiAl alumide titan, carried out by EBW with utilization of LTT with transversal ellipsoidal scanning:
a — face side; *b* — root weld side



a *b*

Fig. 4. Microstructure of titan aluminide welded joint obtained with EBW (sample thickness is 10 mm): *a* — seam metal central area ×100; *b* — seam metal area ×500

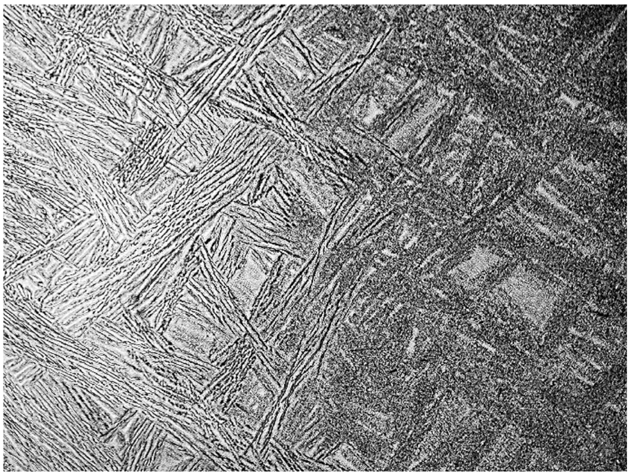
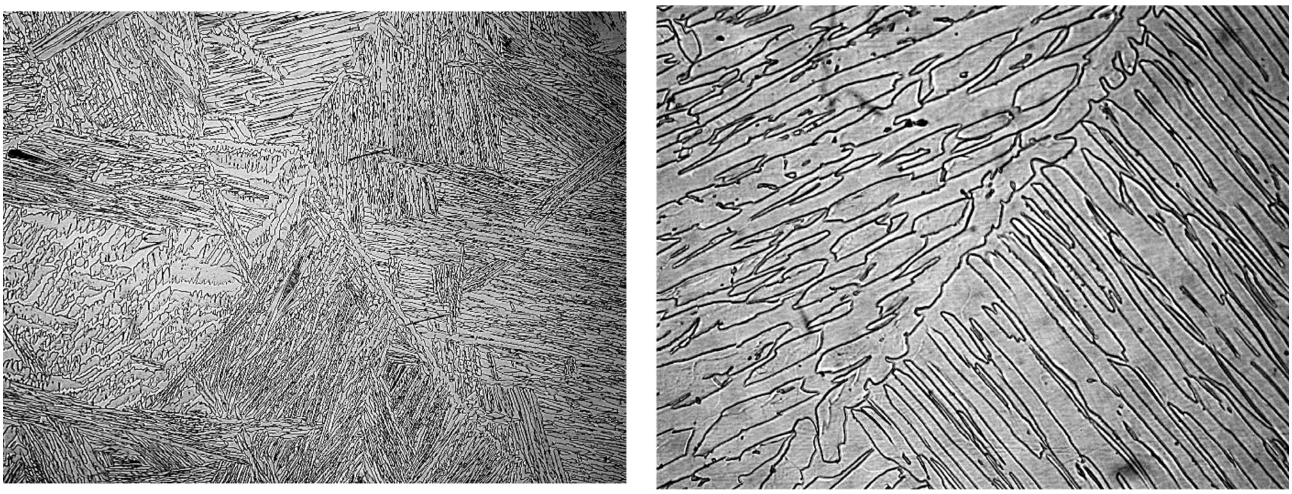


Fig. 5. Microstructure of TAZ area of titan aluminide welded joint, obtained by EBW, ×100

In TAZ area, which borders on the melting line, the needle-shaped structure of α_2-phase is kept. The hardness if this phase is 5,110 MPa, which is at the level of welded seam hardness.

In Fig. 6 the basic metal structure is presented, which consists of clumps of $(\gamma+\alpha_2)$-phase settled at an angle to each other and divided between themselves by boundaries of supposedly β-phase. The hardness of this area is 3,570—3,850 MPa.

There are no defects in the samples investigated is revealed after welding. It may be supposed, that during relatively slow cooling the transformation of α from α-phase area into lamellar $(\gamma+\alpha_2)$-phase take place and some quantity of β_2-phase, which is ordered structure of β-phase, is retain in the alloy, that improve the alloy plasticity, as well as block the origin and splitting of cracks in α_2-phase owing to stresses reduction.



a *b*

Fig. 6. Microstructure of basic metal of titan aluminide welded joint obtained by EBW: *a* — ×100; *b* — ×500

Fractographic investigations of welded joints of TiAl system titan intermetallic compounds realized by EBW

Fractographic investigations were carried out with JSM-840 scanning electron microscope (JEOL Company, Japan) equipped with micro-analyzer of Linksystem 860/500 system (England).

Fractographic investigations of fractures of TiAl system intermetallic compound welded joints samples of 10 mm thickness after compressive tests are shown that under all investigated technological variants the front of main crack was propagated completely perpendicular to the stress loaded.

Rupture of TiAl system intermetallic compound welded joints carried out by LTT with heating $T = 450$ °C, annealing $T = 900$ °C, $t = 5$ min, is mixed in nature. In result of LTT fulfillment the melting line is displayed vaguely and equiaxed grains formation is observed (see Fig. 7, *a*). Analysis of fractographic investigations showed the presence of brittle rupture

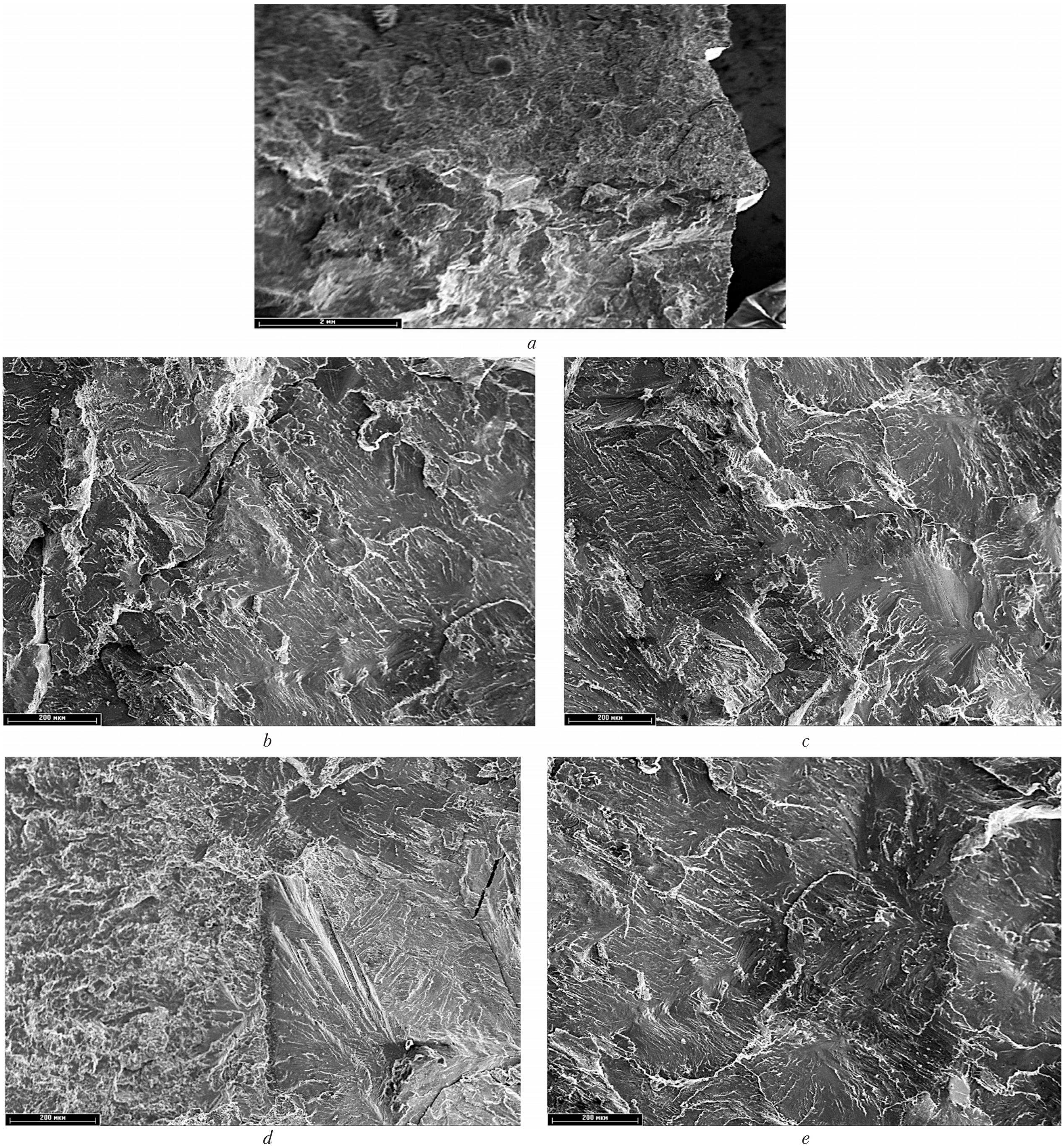


Fig. 7. Fractographic investigations of TiAl system titan intermetallic compound welded joint basic metal by LTT utilization with heating $T = 450$ °C, annealing $T = 900$ °C, $t = 5$ min:
a — welded joint general view ×23; *b* — fracture area, lamellas fragmentation is not take place; *c*, *d*, e — seam metal structure area ×200

areas in quantity about 70 % and ductile rupture areas about 30 %.

Small pits may be observed on the surface of some facets (see Fig. 7, *c*). Its formation is the result of power-consuming pit-connected micro-mechanism of rupture in such zones, where local plastic deformation of metal under load application taken place. It should be noted, that in many areas of intergranular destruction the pits with deformation crests presence are revealed. In addition, the developed relief with relatively smooth facets is revealed on the fracture surface (see Fig. 7, *c*). Presence of ductile component on the rupture surface may be attributed to α_2-phase stability at the expense of β-stabilizers contained in the sample, which facilitate the β-phase formation. Such phase presence in the alloy facilitates the ductile fracture development.

Rupture in basic metal was taken place by stepped way (see Fig. 8, *a*). The steps move ahead in the same direction in parallel to each other manner. Such type of rupture is typical for brittle rupture.

In structure of basic metal of this sample the areas typical for viscous component are also revealed (see Fig. 8, *b*)

Fractographic investigations of fracture surfaces of titan aluminide welded joints samples showed, that for titan aluminide welded joints samples of 10 mm thickness the surfaces have mixed character of rupture (with 30 % viscous component).

The conclusion can be drawn, that this welded joint of TiAl system intermetallic compound with heating T = 450 °C, annealing T = 900 °C, t = 5 min, 10 mm thickness by LTT using has mixed character of rupture.

To a definite degree, the material resists the rupture and, consequently, contains some percent of viscosity.

Because in TAZ of these samples the lamellas thickness and length are larger than that in basic metal, it is evidently, that the process of general furnace heat treatment should be carried out immediately after welding fulfillment.

Conclusions

During the investigations carried out it is revealed, that for prevention of transversal cold cracks initiation in titan aluminide welded joints samples with EBW utilization the preliminary LTT heating with subsequent thermal treatment should be carried out.

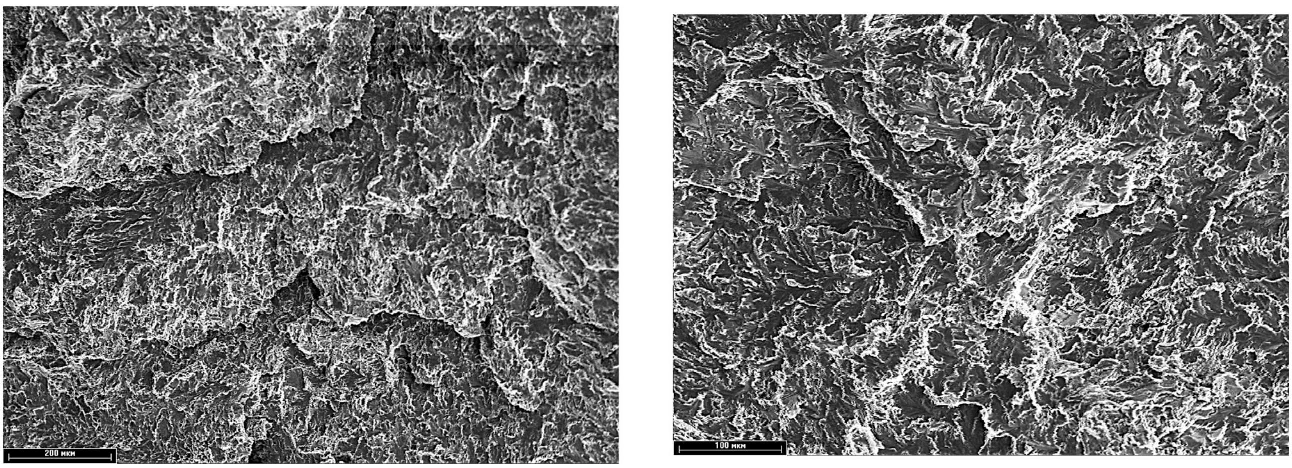
The metallographic investigations fulfilled showed, that during relatively slow cooling the transformation of α from α-phase area into lamellar ($\gamma+\alpha_2$)-phase take place, as well as some quantity of β_2-phase, which is ordered structure of β-phase, is retain in the alloy, that improve the alloy plasticity, as well as block the origin and splitting of cracks in α_2-phase owing to stresses reduction.

Fractographic investigations of fracture surfaces of titan aluminide welded joints samples showed, that titan aluminide welded joints samples have mixed character of rupture (with 30 % viscous component).

Utilization of LTT in EBW process is enough effective and economically justified operation. Such technological operation reduces the level of welding stresses, prevents the cracks initiation, as well as improves the structure and properties of welded joints.

Nomenclature

I — electric current, A
P — pressure, Pa, MPa
T — temperature, deg C, °C
t — time, s, min
U — electrical voltage, V
v — velocity, m·s^{-1}, mm·s^{-1}



a *b*

Fig. 8. Fractographic investigations of TiAl system titan intermetallic compound welded joint basic metal by LTT utilization with heating T = 450 °C, annealing T = 900 °C, t = 5 min:
a — fracture area with stepped development of crack ×100; *b* — area of fracture viscous rupture ×200

Subscriptsand/Superscripts

acc — accelerating
eb — electron beam
weld — welding

Abbreviations

TAZ — thermal action zone
LTT — local thermal treatment
EBW — electron-beam welding

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Вржижевский Э. Л.[1], Пискун Н. В.[1], Таранова Т. Г.[1], Ахонин С. В.[1], Статкевич И. И.[1], Богайчук, И. Л.[1], Зворыкин К. О.[2]

[1] **Институт электросварки имени Е. О. Патона НАН Украины. Украина, г. Киев**
[2] **АО «Украинский научно-исследовательский институт авиационной технологии». Украина, г. Киев**

ПРЕДОТВРАЩЕНИЕ ОБРАЗОВАНИЯ ХОЛОДНЫХ ТРЕЩИН ПРИ ЭЛЕКТРОННО-ЛУЧЕВОЙ СВАРКЕ СПЛАВА НА ОСНОВЕ ИНТЕРМЕТАЛЛИДА СИСТЕМЫ Ti-Al

Проанализированы причины образования холодны трещин, образующихся в сварных соединениях алюминида титана системы Ti-Al пластин толщиной 10 мм при ЭЛС. Установлено, что для предотвращения возникновения поперечных холодных трещин в сварных соединениях образцов алюминида титана, при применении ЭЛС необходимо проводить ЛТО предварительный нагрев с последующей термообработкой. Изучение тепловых процессов при электронно-лучевой сварке и структуры сварных соединений позволили разработать технологию сварки, которая практически исключает образование трещин в сварных соединениях. Разработаны режимы сварки, которые, кроме предотвращения образования трещин, позволяют также получить прочность сварного шва выше прочности основного материала. [dx.doi.org/10.29010/86.6]

<u>Ключевые слова:</u> *алюминид титана; холодные трещины; электронно-лучевая сварка; предварительный подогрев и локальная термообработка сканирование луча; микроструктура; фрактографические исследования.*

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