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INFLUENCE OF THERMAL PROCESSING AND ORIENTATION OF BORIDE FIBERS IN Ti+TiB ALLOY ON MECHANICAL PROPERTIES AND STRUCTURE OF MATERIALS OF Ti+TiB AND (α + β) Ti ALLOYS WELDED JOINT

Processes of electron-beam welding of Ti+TiB and (α + β) Ti alloys, which ensure forming of entire and homogeneous welded joint, are investigated.

Analysis of predominant orientation of TiB reinforcing fibers (along and across of welding samples) on mechanical properties of welded seam is carried out. Peculiarities of microstructure of heat-affected zone and welded seam material are investigated. Effect of welded joint annealing on mechanical strength and ductility of critical structural elements is revealed. [dx.doi.org/10.29010/89.13]

Keywords: *titan alloys; titan boride; metallographic structure; mechanical properties; welded joint; electron-beam welding; thermal treatment.*

Introduction

In previous articles [1–3] the cycle of investigations on Ti+TiB alloys welding is presented. For the welding purposes the electron-beam welding (EBW) was used, which permits to avoid the insertion of foreign elements in the welded seam zone and regulates enough accurately the conditions of welded seam formation. In results of experiments the preferred EBW operation modes were revealed for alloys mentioned, both between each other and with ($\alpha + \beta$) Ti alloy, the T2. At the same time, enough high strength properties of Ti+TiB alloy, ensured by TiB reinforcing fibers, permits to obtain such strength of welded seam, which exceeds the strength of materials under welding.

Problem statement

In case of welding with the T2 alloy the strength of welded joint was determined by the T2 strength [3]. By the composition (Al-3.5%, Nb-3.0%, Fe-2.5%, V-1.9%, Mo-1.4%, Zr-1.3%, Si-0.1%, Ti — the rest) and structure this ($\alpha + \beta$) Ti alloy is close to the T110 alloy, and high mechanical properties of the T110 alloy are reached by the thermal processing [4]. It gives ground to consider that after Ti+TiB — T2 welded joint formation it is expedient to fulfill such thermal annealing, which is traditional for the T110 alloy, and namely this was carried out in the present article with subsequent analysis of mechanical characteristics and metallographic structure of the joint obtained.

For composite type alloys the anisotropy of mechanical properties is typical which is determined by reinforcing fibers directionality. In previous investigations the initial orientation of TiB fibers in Ti was predominantly in the direction perpendicular to the surface under welding. In the present investigation the predominant orientation of TiB reinforcing fibers in the Ti+TiB alloy was the direction parallel to the surfaces under welding. As a sequence, it is necessary to carry out the analysis of reinforced fibers orientation effect in the initial Ti+TiB alloy on properties of the welded joint obtained. The goal of the present investigation is broadening of ways of optimization of mechanical properties of Ti+TiB — T2 welded joints. During the investigation process the task was set to analyze the structural peculiarities of welded materials and welded seam, and to select the structural elements, which effects critically on mechanical strength of the joint obtained.

Results of investigation

The welding was carried out in the following mode of operation: $U_{acc} = 60$ kV, $I_{eb} = 90$ mA. Electron beam movement velocity: $v_{eb} = 7$ mm · s^{-1}, beam sweep — elliptical, transversal (3×4 mm). After welding a part of welded samples were subjected to annealing during 1 hour at the temperature 750°C (in air condition) or at the temperature 850°C (in vacuum). Mechanical tensile test was carried out (GOST 1497-84) with a tensile testing plant ZD-4 (ЦД-4).

For analysis of structural peculiarities of welded joint area the РЭМ-106И scanning electron microscopy and X-ray microstructure analysis were used.

Results of mechanical tests of Ti+TiB — T2 welded samples before and after thermal processing are in the Table 1. The results obtained permit to confirm that under transversal orientation of TiB reinforcing fibers the level of mechanical characteristics of the joint obtained is decreased and critical in the welded joint, in the view of fracture, become the Ti+TiB alloy. In all cases of such predominant orientation the fracture took place in the section of this alloy, at that the fracture character was brittle. The thermal annealing fulfillment at the temperature 750°C (1 hour) permits only to reach some ductility of this critical element of welded construction (see the Table 1).

Regarding the beginning of plastic deformation processes occurring, before the 1–4 sample fracture, may testify the results of fractometric analysis of fracture surface (see Fig. 1). Comparison of morphology of fracture surfaces of the 1–3 sample characterized with $\sigma_в = 931.3$ MPa (see Fig. 1*a*) and the 1–4 sample characterized with $\sigma_в = 970.5$ MPa with δ reached to 2% (see Fig. 1*c*), permit to confirm that in both cases the brittle fracture was initiated by development of brittle crack at the boundary between TiB fiber — titanium matrix. Evidence of this may be TiB fibers revealed which were present at all fracture surfaces (see Fig. 1*b* and Fig. 1*d*). Increase of specific area of TiB fibers cross-section in cross-section area of deformed sample, when fiber orientation is transversal, results in increase of brittle crack nucleus development in such areas namely and, correspondingly, results in the strength decrease. At the fracture surfaces of the 1–4 samples some traces of plastic deformation are observed also (see Fig. 2), which are absent in the 1–3 and 1–5 samples.

Thermal processing, which leads to the increase of strength of Ti+TiB — T2 welded samples, results in changes in metallographic structure of welded samples. The welded sample may be conditionally divided into the following zones:

- initial welded materials,
- welded seam zone, melted by electron beam,
- heat affected zone, located in zone of contact of the welded seam melt with materials under welding, retained solid state condition.

In Fig. 3 the microstructure of material in Ti+TiB — T2 welded joint area in Ti+TiB — welded seam is presented. Comparative metallographic analysis shows that after electron beam welding fulfillment the dark color boron-containing inclusions are observed in zone of crystallization of welded seam melt contacting with

Table 1

Mechanical characteristics of Ti+TiB alloy and T2 titan alloy welding joints obtained by electron-beam welding

Sample No.	Kind of welded joint	Thermal processing	Parameters of electron beam welding			Mechanical characteristics				Structure of material in the welded seam zone	Note
			Electron beam movement velocity v_{eb}, mm · s^{-1}	U_{acc}, kV	I_{eb}, mA	$\sigma_{0.2}$ MPa	$\sigma_в$ MPa	δ %	Ψ %		
1–2	(Ti+TiB) — T2	Without annealing	7	60	90	918.9	991.5	1.2	2.3	Longitudinal reinforcing fibers [3]	Fracture by T2 alloy
1–3		Without annealing				–	931.3	–	–	Transversal reinforcing fibers Fig. 1	Fracture by (Ti+TiB) alloy
1–4		Annealing 750°C 1 hour (air)				928.7	970.5	2.0	5.9	Transversal reinforcing fibers Fig. 2	Fracture by (Ti+TiB) alloy
1–5		Annealing 850°C 1 hour (vacuum)				–	975.7	–	–	Transversal reinforcing fibers Fig. 3	Fracture by (Ti+TiB) alloy

Ti+TiB alloy retained solid-state condition (see Fig. 4*a*). These inclusions have the dimensions from submicron quasi-spherical, segregated into boundary clusters, up to micron, which are close toinitial reinforcing TiB fibers.

Annealing fulfillment at 750°C (see. Fig. 3*b*) and at 850°C (see. Fig. 3*c*) results in dissolution of abovementioned quasi-spherical formations and retaining of part of initial TiB reinforcing fibersin this zone (see Fig. 4*b*). In such boundary zone the submicron reinforcing TiB fibers are formed (see Fig. 5), which are more uniformly distributed after annealing at 750°C and which forms a network of clusters after annealing at 850°C, that is typical for all material of welded seam (see Fig. 6). Dissolution of boron-containing inclusionsin heat affection zone of the Ti+TiB — welded seam system under subsequent relatively short-term annealing is evidence of thermodynamic instability of these clusters. In [5] it was revealed the meta-stable TiB_2, which formation is possible from Ti–B liquid phase at ~2200°C and decomposition take place under conditions of thermodynamic stabilization at ~1800°C. Very likely, under condition of electron beam welding fulfillment the increased heat removal at Ti+TiB — welded seam melt boundary results in fast crystallization and meta-stable phase forming in this zone, which is decomposed during the annealing at 750–850°C (1 hour).

As far from the Ti+TiB — welded seam zone, the influence of annealing fulfilled on welded seam material structure cease be noticeable. Meshes of network of boron fibers submicron clusters are increased in dimensions (see Fig. 7) and are absent in zone of T2 alloy retained in solid-state condition. In welded seam zone the submicron fibers of borides do not have predominant directions in welded sample, but are oriented predominantly along boundary of network of their clusters.

X-ray spectral microanalysis of reinforcing fibers carried out in the welded seam zone do not result in revealing of alloying elements in it, which is typical for the T2 alloy, besides of Al up to 0.18 at.% and Fe up to 0.1 at.%.

Conclusions

1. Fulfillment of electron-beam welding in the following mode of operation: U_{acc} = 60 kV, I_{eb} = 90 mA, electron beam movement velocity: v_{eb} = 7 mm · s^{-1}, beam sweep — elliptical, transversal (3×4 mm), ensures formation of entire and homogeneous welded seam of the Ti+TiB — T2 alloy joint.

2. Under predominant transversal orientation of TiB reinforcing fibers in the Ti+TiB alloy the level of mechanical characteristics of the Ti+TiB — T2 alloy joint obtained is decreased. Critical element in welded joint, in the view of fracture, is Ti+TiB alloy, which

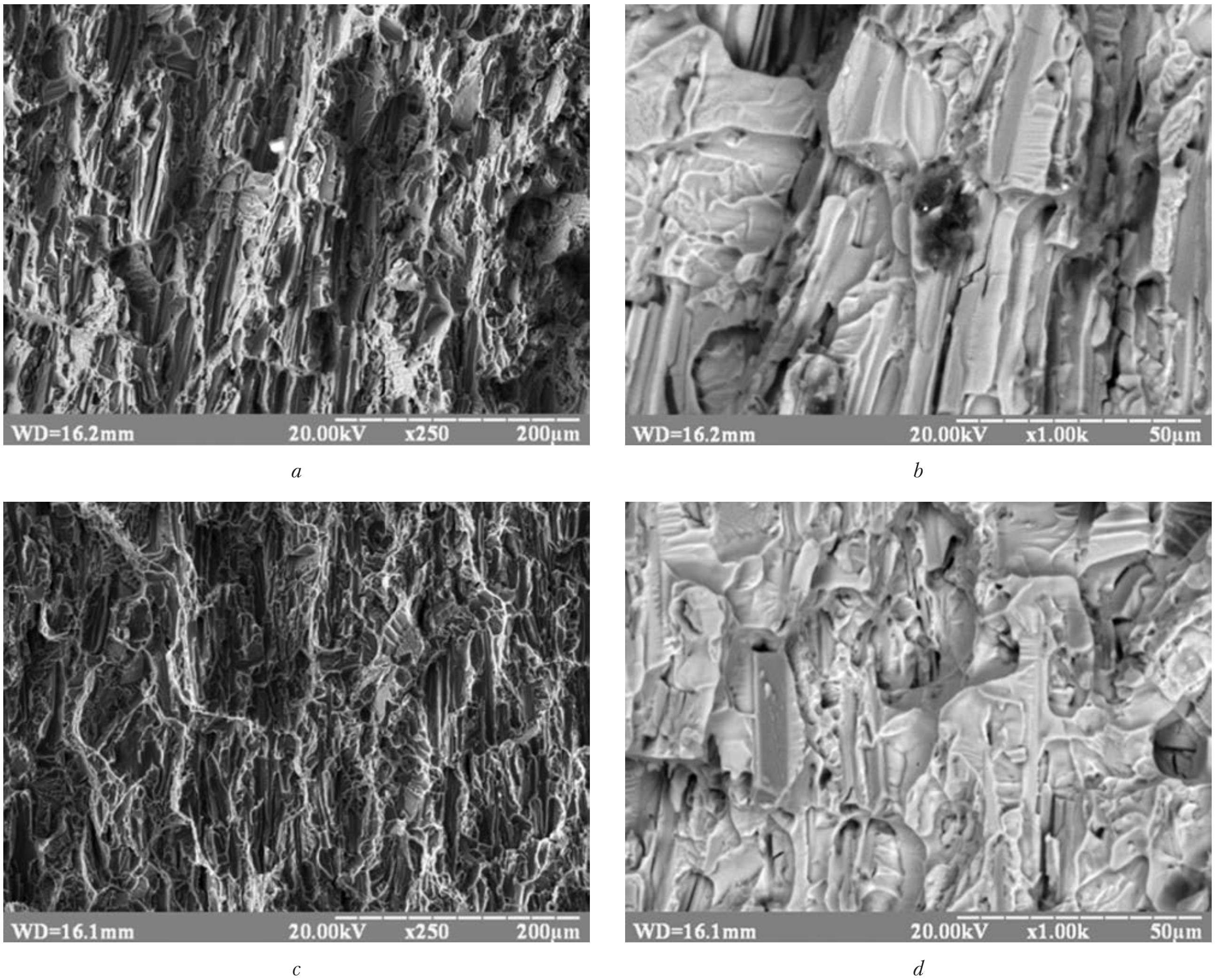


Fig. 1. Structure of fracture surface for 1–3 (*a*, *b*) and 1–4 (*c*, *d*) samples

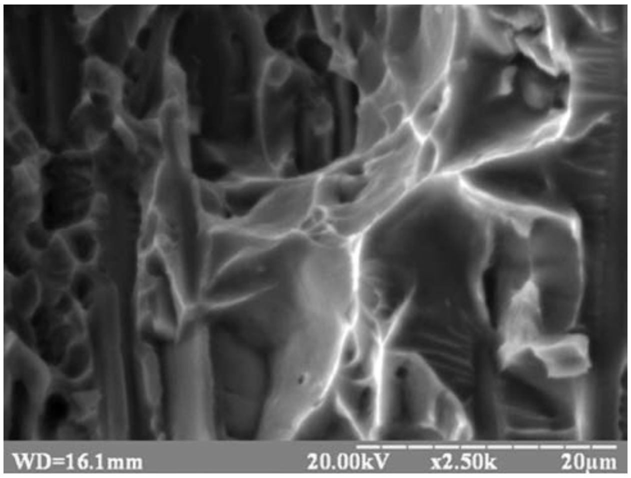
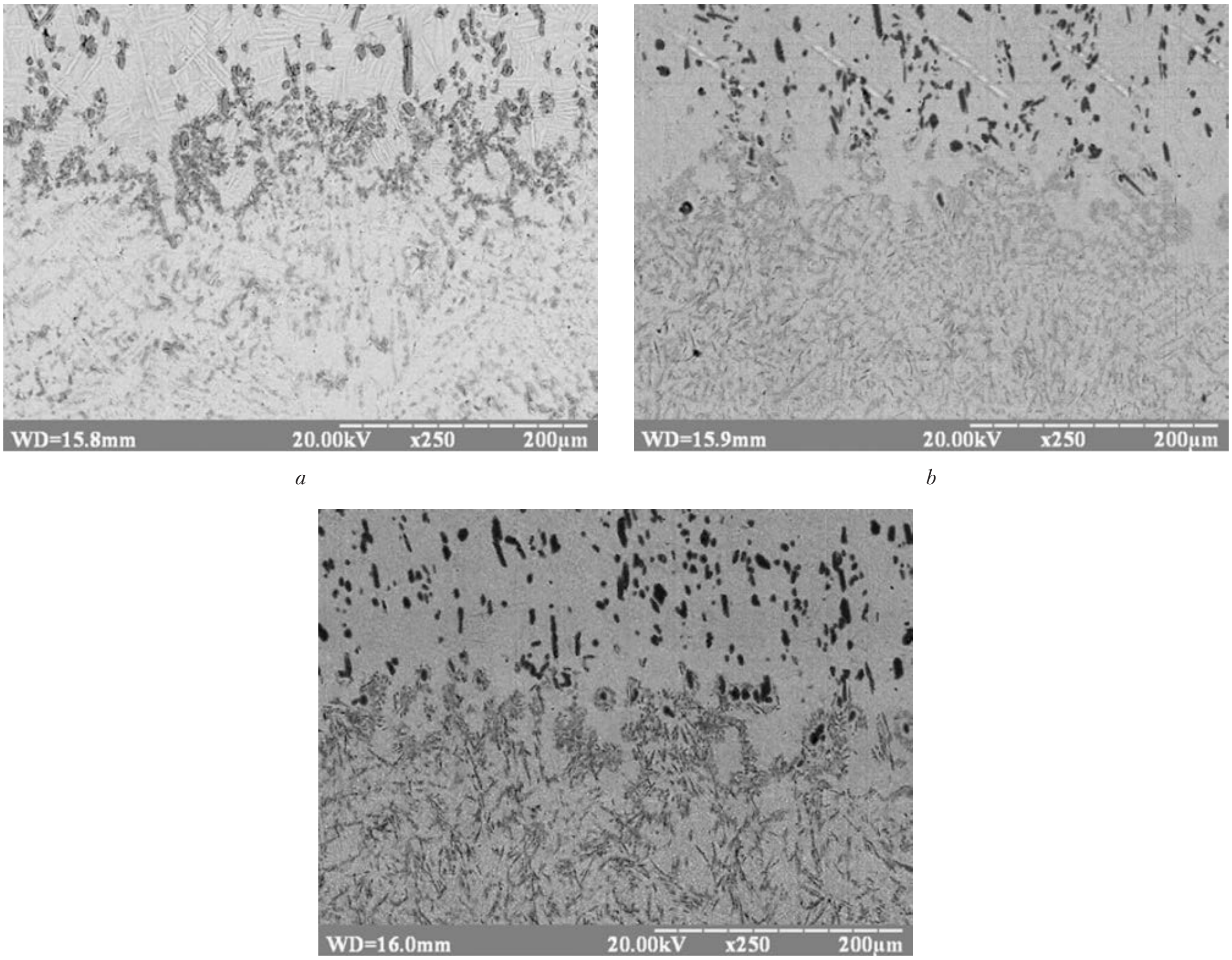


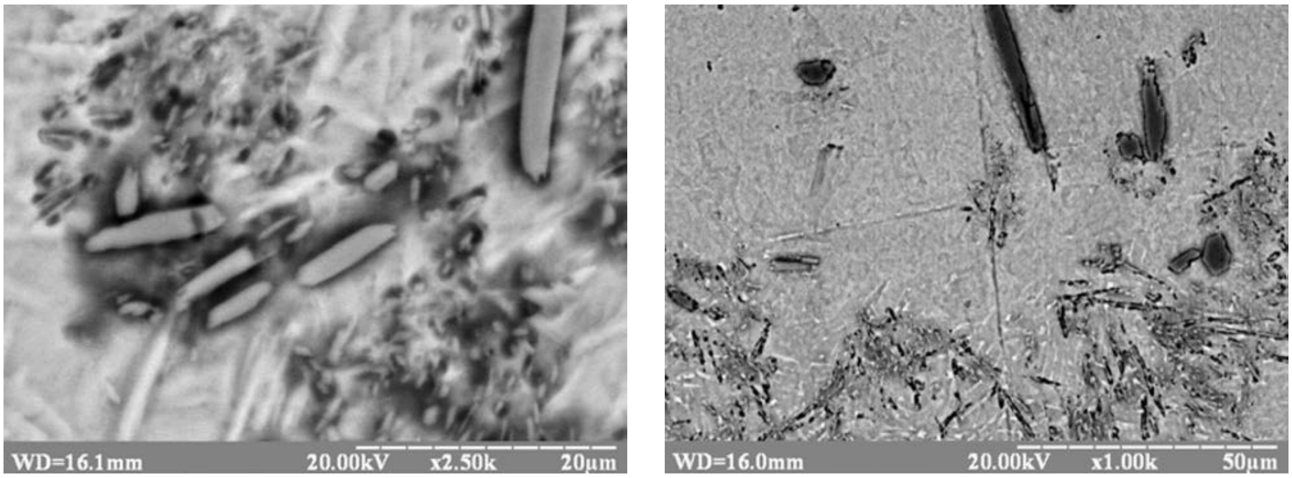
Fig. 2. Traces of plastic deformation on fracture surface of 1–4 sample



a *b*

c

Fig. 3. Microstructure of material in Ti+TiB — T2 joint area in Ti+TiB — welded seam zone:
a — 1–3 sample; *b* — 1–4 sample; *c* — 1–5 sample



a *b*

Fig. 4. Boron-containing inclusions inTi+TiB — T2 joint area in Ti+TiB — welded seam zone:
a — after electron-beam welding (1–3 sample); *b* — after electron-beam welding and subsequent annealing at 850°C (1–5 sample)

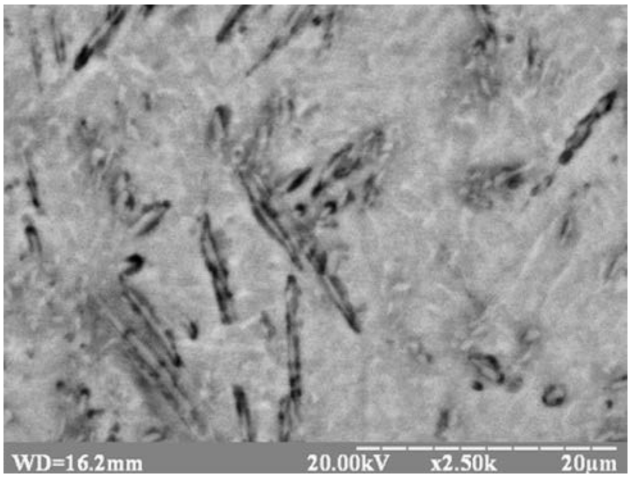


Fig. 5. Submicron reinforcing TiB fibers in Ti+TiB — T2 joint area in Ti+TiB — welded seam zone after annealing at 750°C

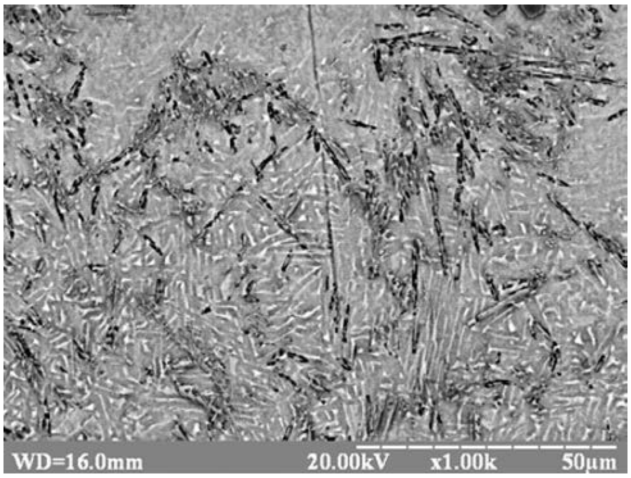
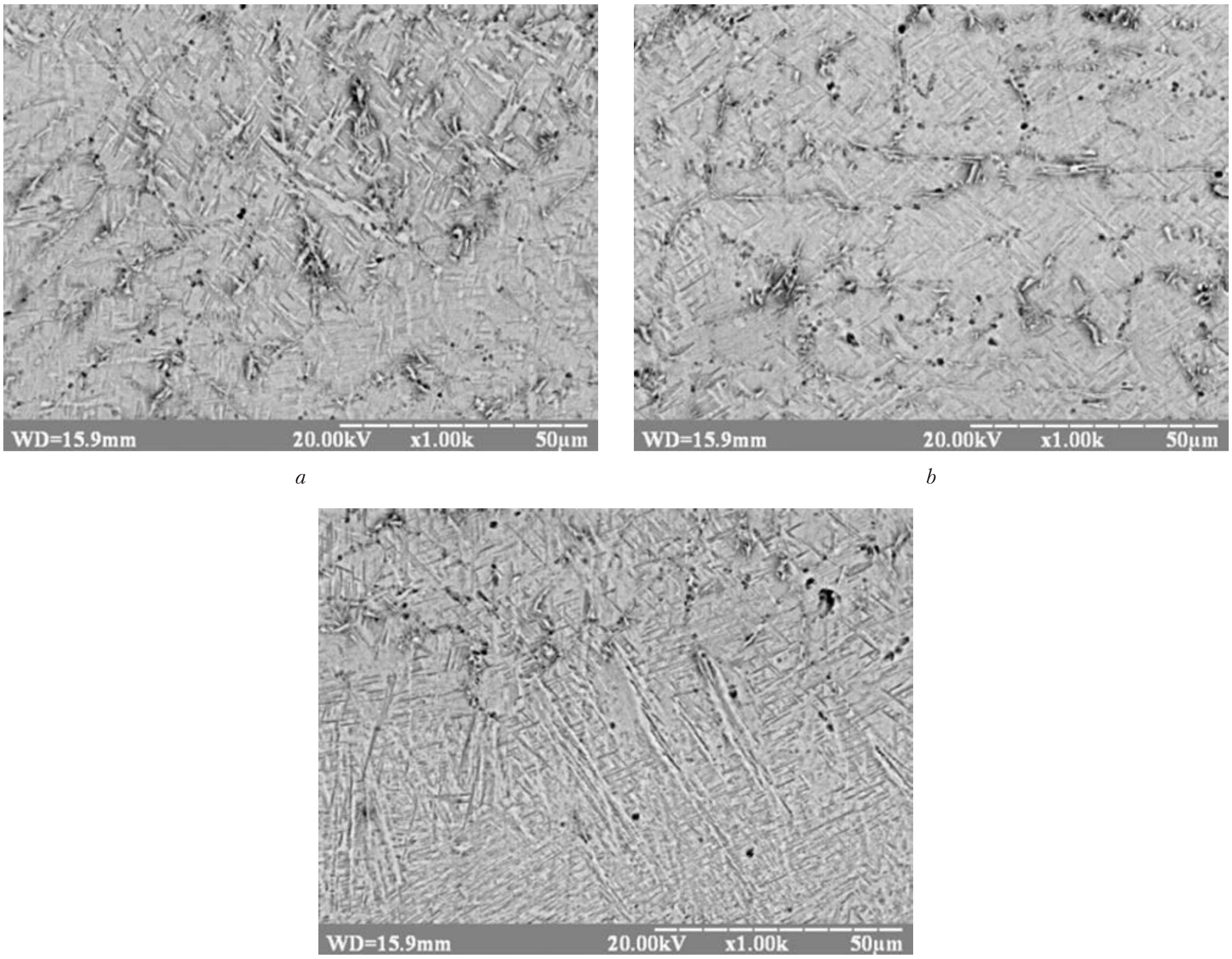


Fig. 6. Network of TiB reinforcing fibers clusters in Ti+TiB — welded seam zone after annealing at 850°C



a

b

c

Fig. 7. Structure of meshes of boride fibers submicron clusters network as far from Ti+TiB — welded seam zone: *a* — welded seam zone located on the side of Ti+TiB — welded seam; *b* — welded seam zone located on the side of T2 alloy — welded seam; *c* — welded seam zone located at the boundary of T2 alloy — welded seam (T2 alloy is in the lower part)

has brittle character of fracture. Fulfillment of thermal annealing of welded joint at 750°C (1 hour) permits to reach some ductility of this critical element of welded construction.

3. Under predominant transversal orientation of TiB reinforcing fibers in the Ti+TiB alloy the critical microstructure elements, initiated the brittle fracture of Ti+TiB — T2 alloy joint, are TiB reinforcing fibers in the material under welding. The secondary TiB reinforcing fibers, formed in the welded seam zone, are of submicron character and are not structural element initiating brittle fracture in the welded seam zone.

Nomenclature

I — electric current, A
T — temperature, degC, °C
U — accelerating electrical voltage, V
v — velocity, $mm \cdot s^{-1}$, $m \cdot s^{-1}$

Greek Symbols

$\sigma_{\text{в}}$ — tensile strength, MPa
$\sigma_{0.2}$ — yield strength, MPa
δ — specific elongation, %
ψ — specific contraction, %

Subscripts and Superscripts

acc — accelerating
eb — electron beam

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ВЛИЯНИЕ ТЕРМИЧЕСКОЙ ОБРАБОТКИ И ОРИЕНТАЦИИ БОРИДНЫХ ВОЛОКОН В СПЛАВЕ Ti+TiB НА МЕХАНИЧЕСКИЕ СВОЙСТВА И СТРУКТУРУ МАТЕРИАЛОВ СВАРНОГО СОЕДИНЕНИЯ Ti+TiB И (α + β) Ti СПЛАВОВ

Исследованы процессы электроннолучевой сварки Ti+TiB и (α + β) Ti сплавов, обеспечивающие формирование сплошного и однородного сварного шва.

Проведен анализ влияния преимущественной ориентации армирующих TiB волокон (вдоль и поперек свариваемых образцов) на механические свойства сварного соединения. Исследованы особенности микроструктуры материала околощовной зоны и сварного шва. Обнаружено влияние отжига сварного соединения на механическую прочность и пластичность критических элементов конструкции. [dx.doi.org/10.29010/89.13]

Ключевые слова: *титановые сплавы; борид титана; металлографическая структура; механические свойства; сварное соединение; электроннолучевая сварка; термическая обработка.*

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