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Structural regularities of welded seam between Ti-Tib and vanadium with 12X18H10T interlayer by using electron beam welding

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Abstract. *Possibilities of obtaining and using an intermediate layer for joining of Ti-TiB and austenitic steel 12X18H10T (analog of AISI 321; 1.4541; X10CrNiTi18-10) were studied. An alloyed interlayer with TiB reinforcing fibers and the main alloying elements of 12X18H10T steel was formed on the surface of the Ti-TiB sample. Such interlayer was formed during electron beam welding of Ti-TiB with vanadium using foil made of 12X18H10T steel. The microstructure of the interlayer consists of a metal matrix reinforced with microfibers. It's composition corresponds to vanadium-alloyed titanium boride. In comparison to the initial Ti-TiB alloy, significant grinding of reinforcing boride microfibers in the interlayer microstructure was observed. Besides, the phase formations close to Ti2B in zone of primary titanium borides decomposition in the interlayer, initiated by electron beam were determined. As a result, application of Ti (63–68 at. %) and V (18–25 at. %) based interlayer with alloying additives (Fe, Cr, Ni, B, C) has great potential for utilization in electron-beam welding of 12X18H10T steel with Ti-TiB alloy.*

Keywords: *titanium; titanium boride; vanadium; interlayer, metallographic structure; welded joint; electron-beam welding; welding parameters*

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1. Introduction

In the present article some basic regularities and optimization directions of Ti-TiB$_n$ alloys welded joints using both with titanium alloys, and other structural materials, were investigated. The Ti-TiB alloys are characterized by composition type structure, such as titanium matrix reinforced by TiB microfibers [1–2] with high mechanical properties [3–4]. Therefore they can be used for joining of main materials used in mechanical engineering. The possibilities of Ti-TiB alloy welded joints using the same alloys as well as other titanium alloys for electron-beam welding are shown in [5]. Optimization of welding parameters allowed to obtain welded joints with strength characteristics comparable to the based materials.

At the same time, for formation of welded joint of Ti-TiB alloy with 12X18H10T steel (analog of AISI 321; 1.4541; X10CrNiTi18-10) the use of niobium and low-carbon steel interlayers were needed [6]. It ensured the obtaining of permanent joint, but the level of mechanical characteristics was considerably less than properties of materials subjected to welding.

2. Problem statement

Utilization of interlayers from materials with high solubility in welded materials is a well-known processing method [7–9]. In case of welding of 12X18H10T austenite steel with such materials as niobium or vanadium, the creation of high thermal stresses in heat affected zone is stipulated by large difference in coefficients of thermal expansion. Perhaps, the easiest way to solve the problem of forming an intermediate layer in a welded joint is to form

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an alloyed layer on the surface of the sample of Ti-TiB alloy, containing reinforcing fibers TiB and the basic alloying elements of steel 12X18H10T.

3. Materials and Methods

In order to solve the this problem, the Ti-TiB alloy specimens (see the Fig. 1) of 50×50×10 mm size were used. There were connected by 50×10 mm edge with vanadium plate of 2×50×10 mm size through the foil of 12X18H10T steel.

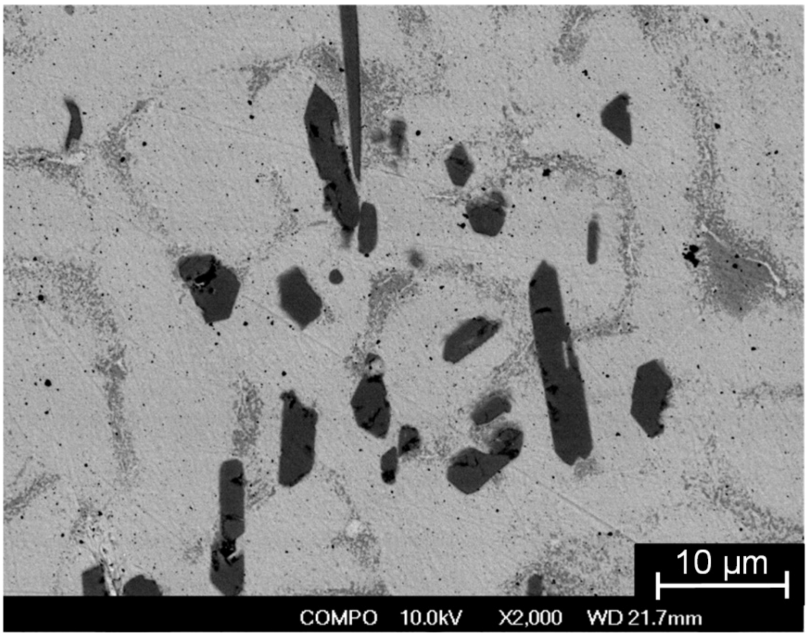


Fig. 1. Microstructure of Ti-TiB alloy

The manufacturing method of Ti-TiB alloy and its specimens is described in [5–6]. The foil of 12X18H10T steel has 0.1×50×10 mm sizes according to the GOST 4986-79 state standard; The vanadium plates had 99.9 % purity (the material contains near 0.98 % of C in form of vanadium carbide, see the Fig. 2) from HMW Hauner GmbH&Co.KG. Results of carbide inclusions composition analyses are presented in the Table 1.

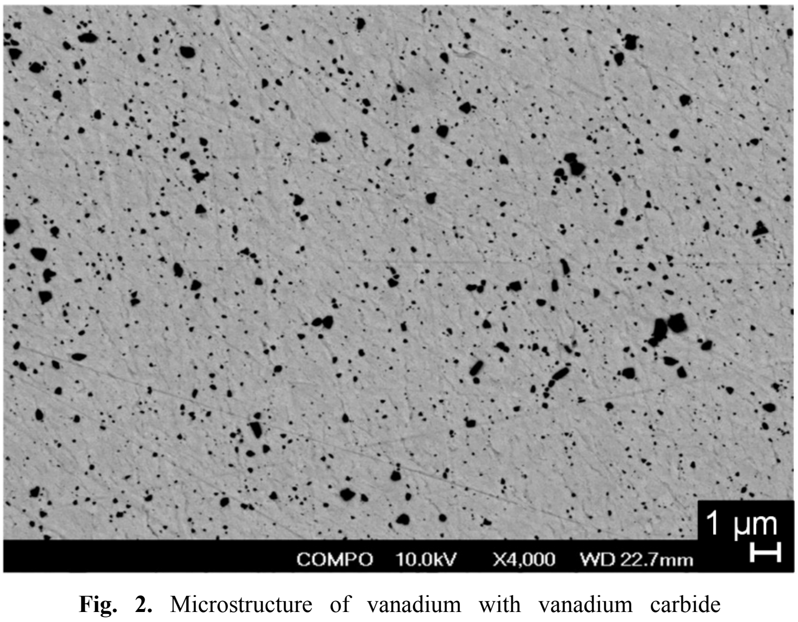


Fig. 2. Microstructure of vanadium with vanadium carbide inclusions

Table 1. Elemental composition of carbide inclusions in vanadium plate

Elemental analysis point	C, at. %	V, at. %
1	40.17	59.83
2	66.30	33.70
3	42.52	57.48
4	66.97	33.03

Electron-beam welding was carried out on UL-144 (УЛ-144, Pilot Paton Plant, Ukraine) welding machine. The welding was carried out using the following mode of operation: U_{acc} = 60 kV, I_{eb} = 90 mA, electron beam movement velocity was v_{eb} = 13 mm·s^{-1}, beam sweep during titanium alloys welding with refractory metals and steels was circular, 0.5 mm in diameter. Distance from the electron beam to the welded joint was 70 mm. Beam spot was displaced towards Ti-TiB alloy by the distance ~ 0.3 mm.

Specimens for metallographic investigations were cutted using a precision water jet cutter KGA 2-R-2500 (КГА 2-Р-2500, Private Enterprise "Roden", Ukraine) in plane perpendicular to the joint surface and subsequent grinding and polishing of cutting surface. For metallographic investigations the specimens were etched with solution: 15 % HF + + 55 % H_2O + 30 % HNO_3.

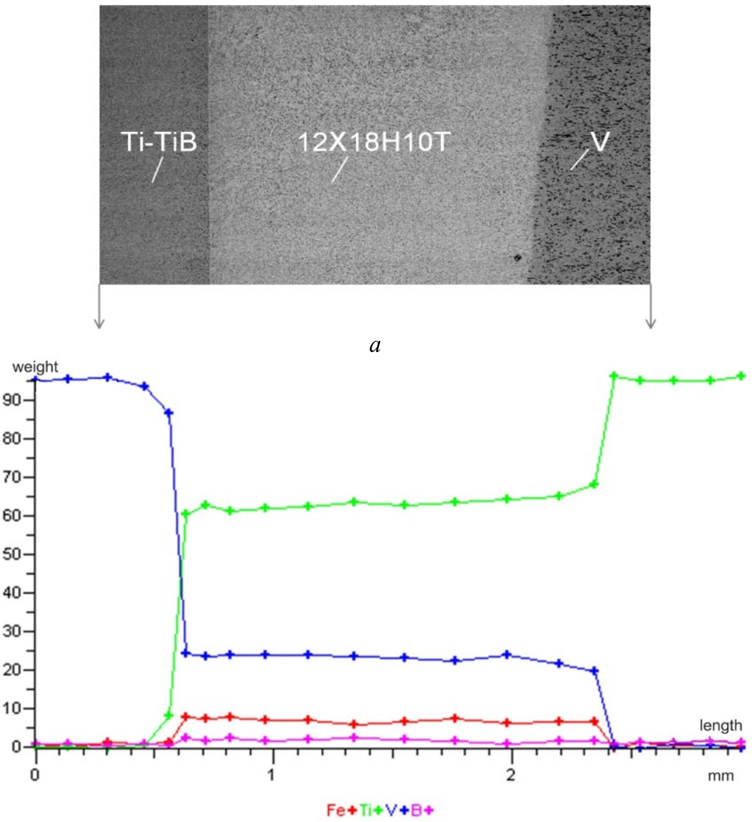
Metallographic investigations were carried out with utilization of the JAMP-9500F (JEOL Ltd., Japan) scanning electron microscope with the OXFORD EDS INCA Energy 350 (OXFORD INSTRUMENTS INDUSTRIAL PRODUCTS LIMITED, Abingdon, Oxfordshire, United Kingdom) energy-dispersive Auger-spectrometer, as well with the JSM-840 scanning electron microscope (JEOL Ltd., Japan) with probe for X-ray microanalysis. Different modes of image obtaining were used for metallographic analysis: in secondary electrons (SEI), in backscattered electrons (BSE) and with characteristic X-ray emission. At that, surface image in backscattered electrons was formed in the following modes: topographic (BSE TOPO), representing the relief, and COMPO, representing the phase components contrast.

4. Results and Discussion

In the Fig. 3 the metallographic structure and distribution character of main elements, in direction perpendicular to the surface of Ti-TiB – 12X18H10T – V connection joint, is presented.

The obtained results are the evidence of formation between vanadium and Ti-TiB alloy the interlayer of alloy based on Ti (63–68 at. %) V (18–25 at. %) with alloying additions Fe (6–7 at. %), B (1.5–2.2 at. %), Cr (5–7 at. %), C (0.6–1.1 at. %), Ni (0.27–1.12 at. %). The interlayer is solid in its character and defect zone is not revealed.

In order to evaluate the utilization of interlayer obtained for Ti-TiB alloy welding with stainless austenite steel (particularly 12X18H10T), it was necessary to analyze its structure. In the Fig. 4 the microstructure of Ti (63–68 at. %) and V (18–25 at. %) based interlayer with alloying additions is presented.



a

b

Fig. 3. Structure (*a*) and distribution character of main elements along scanning line (see (*a*)) of Ti-TiB – 12X18H10T – V joint (*b*)

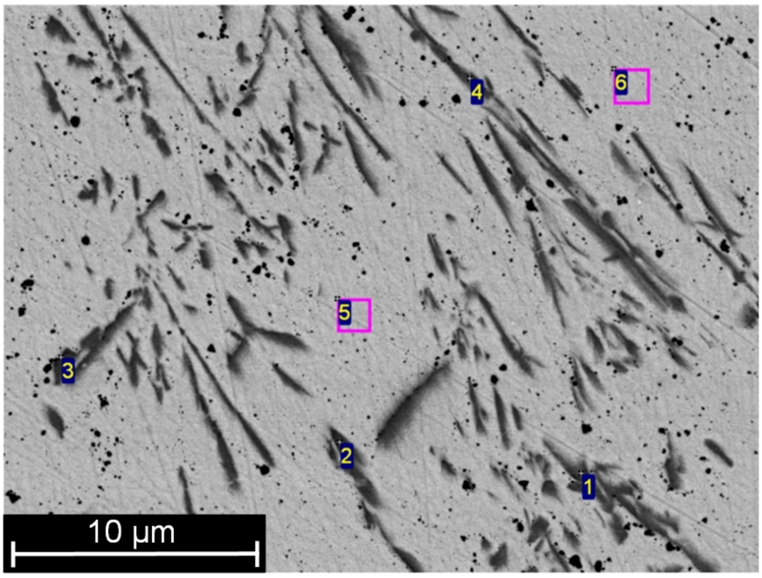


Fig. 4. Microstructure of Ti (63–68 at. %) V (18–25 at. %) based interlayer wit alloying additions (1 – 6 – points of Auger spectral analysis of elemental composition)

Revealed microstructure of formed Ti (63–68 at. %) V (18–25 at. %) bases interlayer with alloying additions is characterized with pattern of metal matrix reinforced with microfibers, which composition (see the Table 2) corresponds to titanium boride alloyed with vanadium [5].

Table 2. Elemental composition in analyzed points (see the Fig. 4) of interlayer of alloy on base of Ti (63–68 at. %) V (18–25 at. %) with alloying additions

Elemental analysis point	B, at. %	C, at. %	Ti, at. %	V, at. %	Cr, at. %	Fe, at. %	Ni, at.%
1	41.36	1.82	43.59	11.18	0.61	1.19	0.26
2	41.16	1.91	46.03	10.05	0.15	0.24	0.45
3	34.44	5.51	47.96	10.64	0.41	0.97	0.08
4	37.46	1.60	46.88	11.96	0.42	1.55	0.11
5	0.00	2.69	67.31	21.98	0.85	6.04	1.12
6	3.05	3.10	64.15	21.31	1.43	5.91	1.06

Distribution pattern of main elements, revealed in Ti (63–68 at. %) V (18–25 at. %) based interlayer with alloying additions from vanadium plate, Ti-TiB alloy and 12X18H10T steel foil, demonstrates that only at the boundary of interlayer with vanadium and Ti-TiB alloy diffusive character of main elements distribution were observed (see the Fig. 2). At that, the concentration profiles at the boundary with vanadium are characterized with more sharp decreasing character than that at the boundary with Ti-TiB alloy. This is an evidence of considerably more intensive diffusion processes proceeding in Ti-TiB alloy area. It is well-known that in liquid phase the diffusive processes have such intensity which are characterized with diffusion coefficient ~ 10^{-5} $cm^2 \cdot s^{-1}$ [10]. Intensity of such processes depends considerably less from temperature and type of migrating atoms, than in solid state. Probably, the considerable differences in concentration profiles at the boundary between interlayer with vanadium and Ti-TiB alloy are witness of momentary presence of material in liquid state in these boundary areas.

Distribution pattern of main elements by interlayer thickness is even, which is usually observed at maximum duration of diffusion processes proceeding. At the electron beam movement velocity v_{eb} = 13 $mm \cdot s^{-1}$ the duration of diffusion processes is determined mainly by residual warming up. In area of formation of Ti (63–68 at. %) V (18–25 at. %) based interlayer with alloying additions the elements redistribution is determined, seemingly, by convection processes caused by electron beam movement.

The microstructure of contact area of Ti (63–68 at. %) V (18–25 at. %) based interlayer with alloying additions and Ti-TiB alloy with distinctive distribution of main chemical elements is presented in the Fig. 5. For more precise determination of distribution by boron, the analysis was carried out by rectangular areas (see the Fig. 5).

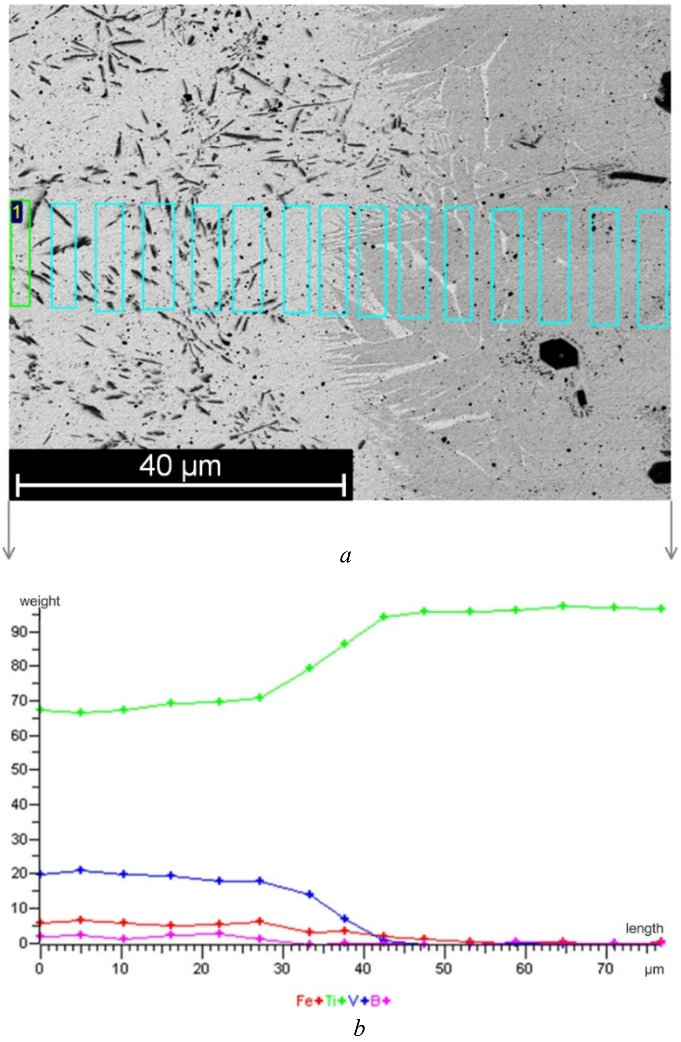


Fig. 5. Microstructure of area of contact of interlayer (*a*) alloy on base of Ti (63–68 at. %) V (18–25 at. %) with alloying additions and Ti-TiB alloy with distinctive distribution (*b*) of main chemical elements

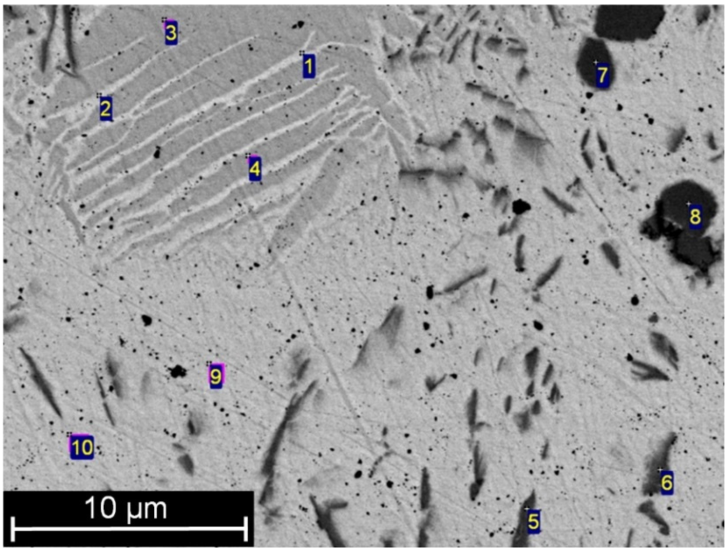


Fig. 6. Microstructure of Ti (63–68 at. %) V (18–25 at. %) based interlayer with alloying additions and Ti-TiB alloy with marks of analysis of elemental composition of the main structural elements

It should be noted, that the appearance of microstructure of transient zone of the Ti (63–68 at. %) V (18–25 at. %) based interlayer with alloying additions and Ti-TiB alloy is very close to the microstructure of “welded seam” – “basic material” transient zone in welded joint of Ti-TiB alloy obtained by electron-beam welding [5]. The formation of molten metal borides can be observed in the melted areas of materials. The size of molten metal borides is considerable less, than in the initial Ti-TiB alloy. Their location is random and any predominant orientation of fibers was not observed.

Analysis of the main distinctive areas of transient zone was carried out. In the Fig. 6 the microstructure of such area with elemental analysis points 1 – 10 selected is presented. Results of analysis are in the Table 3.

Table 3. Elemental composition of Auger spectral analysis points (Fig. 6), corresponding to the main elements of microstructure of contact area of interlayer alloy on base of Ti (63–68 at. %) V (18–25 at. %) with alloying additions and Ti-TiB alloy

Elemental analysis point	B at. %	C at. %	O at. %	Ti at. %	V at. %	Cr at. %	Fe at. %	Ni at. %
1	0.71	2.78	3.02	83.88	1.66	0.53	6.22	1.19
2	0.00	3.39	6.35	76.82	5.72	0.65	6.14	0.92
3	0.00	3.93	2.77	91.82	0.00	0.44	0.94	0.11
4	0.25	4.33	2.17	92.37	0.00	0.21	0.47	0.19
5	40.40	1.88	0.00	47.51	9.22	0.20	0.52	0.27
6	45.00	2.34	0.00	42.72	9.04	0.19	0.63	0.07
7	45.26	1.34	0.00	52.68	0.10	0.00	0.43	0.20
8	47.25	2.00	0.00	49.75	0.32	0.13	0.56	0.00
9	0.00	2.95	0.00	74.98	16.03	0.74	4.30	0.99
10	1.66	3.98	0.00	70.39	17.73	0.72	4.47	1.05

Elongated bright phases (points 1, 2), according to the iron – titanium phase diagram [11], correspond to α-hard solution. Darker phase, which in appearance is close to the titanium matrix of Ti-TiB alloy (see point 10), is not typical for main alloy Ti-TiB. Elemental composition of such discharge (see. the Fig. 7) is presented in the Table 4.

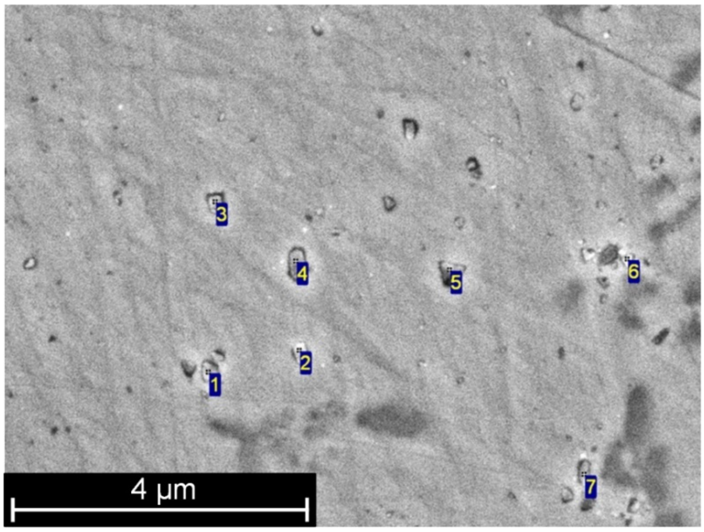


Fig. 7. Carbide-type discharges in titanium matrix of Ti-TiB alloy in area of contact of Ti (63–68 at. %) V (18–25 at. %) based interlayer with alloying additions and Ti-TiB alloy

Table 4. Elemental composition of carbide-type discharges in titanium matrix (see the Fig. 7)

Elemental analysis point	C, at. %	Ti, at. %	V, at. %	Fe, at. %
1	61.20	28.22	8.99	1.60
2	57.82	30.44	9.84	1.91
3	58.74	30.11	9.55	1.61
4	62.51	27.59	8.04	1.86
5	61.40	28.05	9.37	1.19
6	41.82	40.59	13.95	3.64
7	52.06	34.40	10.95	2.59

Submicron clusters of carbide phase of titanium form the eutectic type areas presented in the Fig. 8.

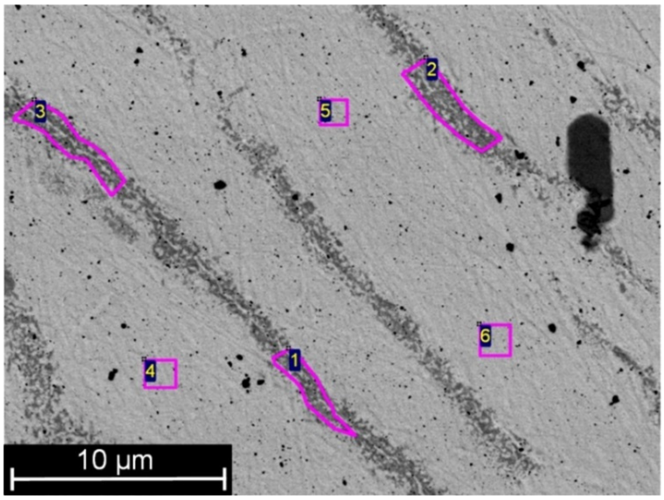


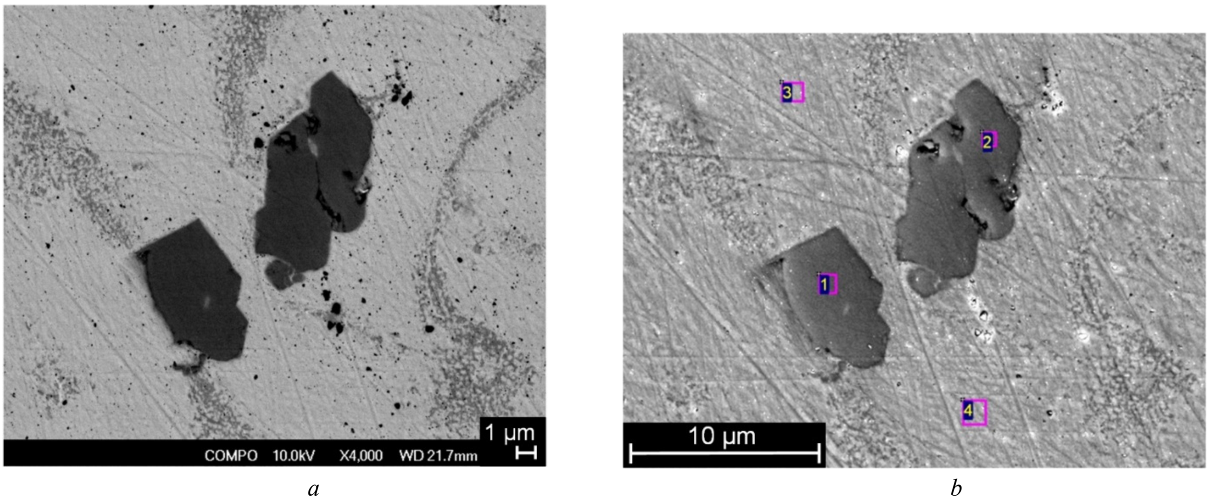
Fig. 8. Elongated areas of submicron carbide clusters of titanium (elemental analyses zones 1 – 3, the Table 5) in titanium matrix of Ti-TiB alloy in zone of contact of interlayer alloy on base of Ti (63–68 at. %) V (18–25 at. %) with alloying additions and Ti-TiB alloy

Table 5. Elemental composition of elemental analysis zones in area of elongated submicron carbide-type inclusions in titanium matrix (see the Fig. 8)

Analysis zone	B, at.%	C, at.%	O, at.%	Ti, at.%	V, at.%
1	1.71	4.22	1.04	93.03	0.00
2	0.00	3.93	2.58	93.49	0.00
3	0.46	4.67	3.63	91.24	0.00
4	1.28	3.91	5.51	89.30	0.00
5	0.00	3.99	3.03	92.30	0.68
6	0.32	3.54	3.31	92.70	0.14

Essential distinction of titanium matrix in area of such microstructure formations of eutectic-like type is the presence of oxygen in it from 1 to 5 at. %. The presence of oxygen in some zones of Ti-TiB alloy, seems to be connected with technology of its manufacture from the powder materials [1–2, 5].

Primary titanium borides in molten zone, formed by thermal action of electron beam, are dissolved and are the source of boron delivery for crystallization of microfibers, which composition fit with titanium boride doped with vanadium (see the Fig. 4). At the boundary of the melt and Ti-TiB alloy the part of TiB fibers is retained (see the Fig. 9), dissolving partly only.



a *b*

Fig. 9. Primary titanium borides in titanium matrix at the boundary of Ti-TiB alloy and interlayer on base of Ti (63–68 at. %) V (18–25 at. %) with alloying additions, with points of elemental analysis 1 – 4 (see the Table 6): (*a*) – image in COMPO mode; (*b*) – image in SEI mode

Table 6. Elemental composition of points of analysis of primary titanium boride and titanium matrix (see the Fig. 9)

Elemental analysis point	B, at.%	C, at.%	O, at.%	Ti, at.%	V, at.%	Cr, at.%	Fe, at.%	Ni, at.%
1	45.11	1.52	0.00	52.70	0.04	0.07	0.52	0.03
2	45.03	1.54	0.00	52.90	0.15	0.04	0.21	0.12
3	0.00	3.77	4.07	91.24	0.37	0.00	0.55	0.00
4	0.00	3.55	4.53	90.47	0.00	0.21	1.25	0.00

Near partially dissolved TiB microfibers the formation of secondary boron-containing fibers were observed (see the Fig. 10), which composition is close to the Ti_2B - meta-stable phase and which existence in welded seam heat affected zone was supposed in [5]. Elemental composition in 1 - 6 points of analysis is presented in the Table 7.

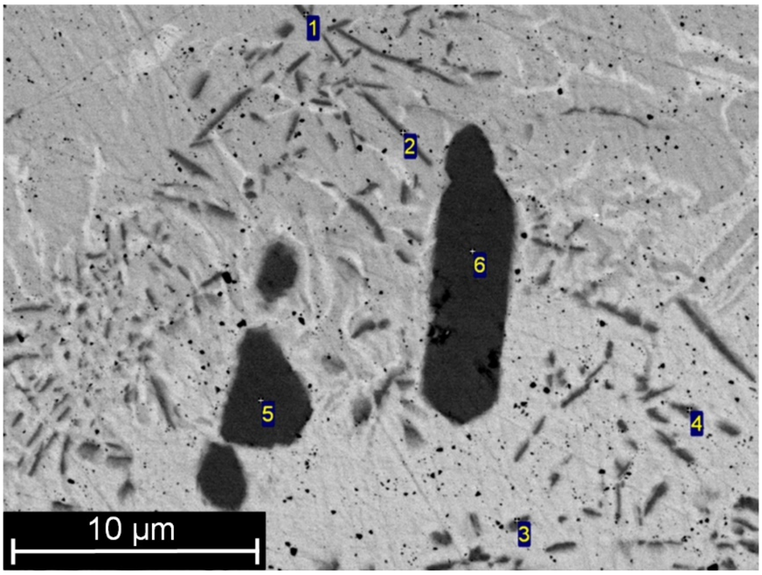


Fig. 10. Formation of secondary boron-containing fibers (analysis points 1 – 4) near partially dissolved microfibers of primary TiB (analysis points 5 – 6)

Table 7. Elemental composition of points of analysis of primary titanium boride and titanium matrix (see the Fig. 10)

Elemental analysis point	B at.%	C at.%	O at.%	Ti at.%	V at.%	Cr at.%	Fe at.%	Ni at.%
1	9.06	0.67	0.00	89.48	0.25	0.00	0.54	0.00
2	5.82	1.36	0.00	91.81	0.00	0.29	0.62	0.10
3	9.44	1.00	0.00	74.30	12.57	0.56	1.68	0.44
4	10.91	0.93	0.00	76.90	9.70	0.20	0.97	0.39
5	16.10	0.79	0.00	81.68	0.51	0.00	0.93	0.00
6	15.66	0.56	0.00	81.34	1.76	0.00	0.69	0.00

Thus, the electron-beam welding of specimens made of Ti-TiB alloy, joined with vanadium plates through the foil of 12X18H10T steel, permits to obtain the Ti (63–68 at. %) V (18–25 at. %) based interlayer with alloying additions (Fe, Cr, Ni, B) reinforced with crushed titanium boride microfibers with increased length/thickness ratio (in comparison with primary borides). In the interlayer formed, which thickness was ~1.7 mm, the structural defects and phase formations, capable to initiate brittle fracture in this zone, are not revealed. Adding of such vanadium and iron interlayer in the material ensures the reduction of iron linear expansive coefficient [11], which results in lowering of thermal stresses level in heat affected zone of Ti-TiB alloy/12X18H10T steel joint, which are critically influenced on mechanical properties of such joint [6].

5. Conclusions

1. Electron-beam welding joint of Ti-TiB alloy with vanadium through foil of 12X18H10T steel permits to ensure the formation of doped interlayer on Ti-TiB alloy surface, which contains TiB reinforcing fibers, as well as the main alloying elements of 12X18H10T steel and vanadium.
2. Microstructure of formed interlayer of alloy on base of Ti (63–68 at. %) V (18–25 at. %) with alloying additions (Fe, Cr, Ni, B, C) is characterized with pattern of metal matrix reinforced with microfibers, which composition corresponds to titanium boride alloyed with vanadium.
3. Characteristic feature of reinforcing boride microfibers in microstructure of interlayer of alloy on base of Ti (63–68 at. %) V (18–25 at. %) is their considerable crushing in comparison with initial Ti-TiB alloy.
4. In interlayer of alloy on base of Ti (63–68 at. %) V (18–25 at. %) with alloying additions (Fe, Cr, Ni, B, C) in zone of primary titanium borides decomposition, initiated by electron beam affecting, the phase formations are revealed, which are close by element composition to Ti_2B.
5. Interlayer of alloy on base of Ti (63–68 at. %) V (18–25 at. %) with alloying additions (Fe, Cr, Ni, B, C), formed on the surface of Ti-TiB alloy, is prospective for realization of electron-beam welding of 12X18H10T steel with Ti-TiB alloy.

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Структурные закономерности формирования сварного шва сплава Ti-Tib с ванадием при наличии прослойки стали 12Х18Н10Т в условиях электронно-лучевой сварки

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Аннотация. *Исследовались возможности получения и использования промежуточной прослойки для выполнения сварного соединения сплава Ti-TiB с аустенитной сталью 12Х18Н10Т (аналоги AISI 321, 1.4541, X10CrNiTi18-10). Для этого на поверхности образца сплава Ti-TiB формировалась легированная прослойка, содержащая армирующие волокна TiB и основные легирующие элементы стали 12Х18Н10Т. Было определено, что такая прослойка получается применением электронно-лучевой сварки соединения сплава Ti-TiB с ванадием через фольгу из стали 12Х18Н10Т. Было выявлено, что микроструктура сформированной прослойки сплава на основе титана и ванадия с легирующими добавками имеет характер металлической матрицы, армированной микроволокнами, состав которых соответствует бориду титана,* *легированного ванадием. Было обнаружено, что для армирующих боридных микроволокон в микроструктуре прослойки сплава на основе титана и ванадия характерной особенностью является их значительное измельчение в сравнении с исходным сплавом Ti-TiB. Кроме того, в этой прослойке в зоне распада первичных боридов титана, инициированного влиянием электронного луча, были обнаружены фазовые образования по элементному составу близкие* Ti_2B*. В результате было сделано предположение, что прослойка сплава на основе Ti (63–68 at. %) и V (18–25 at. %) с легирующими добавками (Fe, Cr, Ni, B, C), сформированная на поверхности сплава Ti-TiB, перспективна для использования для электронно-лучевой сварки стали 12Х18Н10Т со сплавом Ti-TiB.*

Ключевые слова: *титан; борид титана; ванадий; прослойка; металлографическая структура; сварное соединение; электронно-лучевая сварка; параметры сварки.*

Структурні закономірності формування зварного шва сплава Ti-Tib з ванадієм за наявності прошарку сталі 12Х18Н10Т в умовах електронно-променевої зварювання

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Анотація. *Досліджувалися можливості отримання зварного з'єднання сплаву Ti-TiB з аустенітної сталлю 12Х18Н10Т шляхом формування проміжного шару в зварному з'єднанні. Для цього на поверхні зразка сплаву Ti-TiB формувався легований прошарок, що містить армуючі волокна TiB і основні легуючі елементи стали 12Х18Н10Т. Було визначено, що такий прошарок одержується застосуванням електронно-променевого зварювання з'єднання сплаву Ti-TiB з ванадієм через фольгу зі сталі 12Х18Н10Т. Було виявлено, що мікроструктура сформованого прошарку сплаву на основі титану і ванадію з легуючими добавками має характер металевої матриці, армованої мікроволокнами, склад яких відповідає боріду титану, легованого ванадієм. Було виявлено, що для армуючих боридних мікроволокон в мікроструктурі прошарку сплаву на основі титану і ванадію характерною особливістю є їх значне подрібнення в порівнянні з вихідним сплавом Ti-TiB. Крім того, в цьому прошарку в зоні розпаду первинних борідів титану, ініційованого впливом електронного променя, були виявлені фазові утворення за елементним складом близькі Ti2B. В результаті було зроблено припущення, що прошарок сплаву на основі Ti (63-68 at.%) I V (18-25 at.%) із легуючими добавками (Fe, Cr, Ni, B, C), сформований на поверхні сплаву Ti -TiB, перспективний для використання для електронно-променевого зварювання сталі 12Х18Н10Т зі сплавом Ti-TiB.*

Ключові слова: *титан; борід титану; ванадій; прошарок; металографічна структура; зварене з'єднання; електронно-променеве зварювання; параметри зварювання.*

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