

Study of metal structure welded on the titanium malleable alloy

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1. Introduction

Titanium is a sufficiently light ($\rho = 4505 \text{ kg/m}^3$), silver-gray color metal. Melting point is near 1665°C . The change of properties from technically pure metal ($\text{Ti} \geq 99.99\%$) to commercially pure ($\text{Ti} \geq 99.0\%$) depend on the impurities in it: R_m - from 240 MPa to 660 MPa; R_e - from 140 MPa to 560 MPa; A from 55% to 25% [1]. The major advantage of titanium lies in the fact that it can be used at low temperatures (to -253°C), and has high corrosion resistance at high temperatures (to 400°C). The main disadvantage of titanium is lower (in comparison with steel) Young's modulus [$\sim(1,1-1,3) \cdot 10^5 \text{ MPa}$] and high cost (20.000 - 25.000 \$/t).

Titanium alloys BT 1-00, BT 1-0, the alloys YT 5 (Ti-5Al-2,5Sn on CR ISO 15608), etc. are attributed to α -titanium alloys [2-5]. α -titanium is used mostly in chemical industry also for producing welded power units, working in the temperature range from -253°C to $+400^\circ\text{C}$.

Two-phase $\alpha + \beta$ martensite type alloys contain a significant quantity of β -stabilizing elements, but no more than critical concentration. This group includes BT 3-1 (Ti-6Al-2Cr-2,5Mo-Zr on CR ISO 15608), BT 14 (Ti-5Al-3Mo-1V on CR ISO 15608), BT 22 (Ti-5Al-5Mo-5V-1Cr on CR ISO 15608) and others. Depending on the temperature of hardening and content of β -stabilizers either only martensite or α -phase plus martensite, or martensite plus β -phase and other structures is formed. $\alpha + \beta$ alloys of titanium are used for producing fuselages of airplanes and rockets, details of aircraft engines, pressure vessels working in low temperatures, etc. [2-4].

In β -titanium alloys, which contain β -stabilizers (V, Mo, Zr, Ta, Sn, Mn, Fe, Cr, Co, Ni) in quantities equal to or larger than the critical concentration there is no martensite transformation. When heated it can have $\alpha + \beta$ composition. The following alloys according to CR ISO 15608 are attributed to them: Ti-10V-2Fe-3Al, Ti-11,5Mo-6Zr-4,5Sn, Ti-3Al-8V-6Cr-4Zr-4Mo, etc. [2-4]. Machine parts, which are affected by aggressive environment at elevated temperatures, high strength fasteners, details of space apparatus, etc. are made from β -titanium alloys.

Recently we observe active performance studies of alloys with the special property: highly heat-resistant alloys on the basis of compound Ti3Al, alloys with high anticorrosive properties on the basis of TiNi and others. In this case particular attention is paid to the minimum content of harmful impurities (S, P, O₂, N₂, H₂) in alloys.

Most titanium alloys can be fusion welded and all alloys can be joined by solid state processes. Indeed, welds in titanium are substantially immune to many of the weld cracking problems that cause trouble with ferrous alloy fabrications. Despite this and other beneficial characteristics, some engineers still believe that titanium is difficult to weld, possibly due to its particular requirements

with regard to gas shielding, or because it has normally been handled only by specialist fabricators. Titanium is actually easy to weld by most processes, as are most of its more common alloys. Embitterment through contamination with air and carbonaceous materials poses the biggest threat to successful fusion welding titanium, so the area to be welded must be clean and protected by inert gas while hot. The means to protect the weldment with inert gas are commercially available and easy to implement [5].

In MIG welding, an arc is generated between a continuously fed consumable electrode (a wire of matching composition to the base material) and the work piece. Spray transfer occurs above a critical welding current density and requires the use of direct current with the electrode positive. This method demands high currents and therefore high welding speeds, which in turn require long trailing shields, and effectively restricts the process to mechanized welding. Dip transfer, whereby the electrode comes into contact with the weld pool, can be used for semimechanized welding, typically for sheet material, but defects, caused by lack of fusion, can be a problem.

MIG welding offers greater productivity than TIG welding, especially for completing thicker section joints. As yet the process has been typically applied to joints for which exceptional weld quality is not critical, e.g. appliqué armour plate, but with development the process may be capable of satisfying higher quality welding requirements [5].

2. Experimental

When welding BT 3-1 alloy the problem common to all $\alpha + \beta$ alloys appears, that is obtaining the optimal chemical and phase composition of welded joint metal in the case of application of the wires, which differ in composition from the base metal [1-4].

Comparative metallographic analysis was made of the weld bead welded on plates of the alloy of titanium BT 3-1 GOST 19807 ($\alpha + \beta$ - titanium Ti-6Al-2Cr-2,5Mo-Zr on CR ISO 15608) by wire BT 1-0 GOST 19807 (α -titanium). The mechanized welding of the wire of 1.2 mm diameter on titanium plates of 6-12 mm thickness with the help of alternating and direct current was applied. The current of welding varied from 140 A to 180 A. Important for the seams is the content of admixtures of gases (O₂, N₂, H₂) in them. This is related with the higher influence of interstitial impurities on the properties of the cast metal, than on its deformation. The maximum content of gases in seams must be less than in the base metal. This is reached by maintaining the purity of shielding gas and wire. The structure of the weld and zone near the weld was fixed with the help of scanning microscope XL30 ESEM, PHILIPS. Chemical composition of the base and weld materials is represented in Table.

Chemical structure of the base and weld materials, %

Material	C	Ti	Fe	Al	Mo	O	The note
BT 1-0	0.07	99.18-99.70	0.18	-	-	0.12	N = 0.04
BT 3-1	0.10	85.46-91.35	0.2-0.7	5.3-7.0	2.0-3.0	0.18	Zr = 0.5 Cr = 0.8-2.3
Weld metal	0.08	94.23	0.32	3.04	1.21	-	Cr = 1.12

3. Results and analysis

High-strength alloys of titanium are very sensitive to thermal cycles; therefore depending on their parameters the phase composition sharply changes and, as a result, mechanical properties change too. In welding process with the characteristic for it rapid uneven in time heating and cooling rates the properties of metal in these zones change considerably [2, 4, 5].

When welded alloys undergo polymorphous transformation abrupt change in the structure and properties occurs in the dilution zone and the zone near the weld. The sizes of these zones depend on the following basic factors: the method and regimes of welding, composition of alloy, thickness of welded sheets, conditions of welding. Just these zones are determined during the weldability estimation of high-strength alloys of titanium and workability of the welded joints.

When studying structural changes the appearance of a cellular structure is observed at the boundaries of heat-affected zone with the base metal. Approaching the seam, i.e. when the temperature of heating increases, cells increase in dimensions and become clearer. Inside the cell it has the banded structure, which resembles tracks of the duplex structure. A quantity of strips increases proportionally to the distance from the base metal to the seam. This phenomenon is caused by the combined action of temperature and stressed state during welding. The nature of structure changes slightly in temperature boundary of partial phase over-crystallization. During cooling from higher temperatures tempering structures appear. In addition to β -phase and matrix α -phase products of martensite transformation α' or α'' can form.

The basic factor, which influences the properties of dilution zone, is the rate of cooling W_{oxl} . Thus, the most effective and practically acceptable regulation of properties in the zone near the weld is the change of cooling rate in the interval of phase transformations during the welding process.

Comparative studies of microstructure of the weld material and welded zone obtained in the bead formed on plates of titanium BT 3-1 in argon medium were done.

Fig. 1 shows common form of the welds, done during the bead forming on the plates of alloy BT 3-1 by welding with wire BT 1-0 in argon using alternating current. Fig. 2 shows the main metal structure (alloy BT 3-1). The structure of welds of alloy BT 3-1, obtained using wire BT 1-0, is characterized by coarse-grained structure α' -martensite type phase with a small quantity of β -phase (Figs. 3 and 4). It is known from the literature that the greatest plasticity, impact toughness and low tendency towards the delayed fracture after welding have alloyed seams of the structure of finely acicular α' -phase. Majority

of welded structures of $\alpha + \beta$ titanium alloys of the system Ti-Al-V-Zr have the strength of welded connections $R_m = 850-1000$ MPa (after heat treatment $R_m = 1050-1300$ MPa). Zirconium is characterized by high solubility in all modifications of titanium and contributes to comminution of falling out α' -phase.

Fig. 5 shows the fractogram of destruction of the weld, which is characterized by the method of destruction.

Changes of hardness over cross-section of the seams, obtained using alternating and direct currents, have similar data. Maximum hardness was observed in the dilution zone and was 320 HV, the hardness of the base metal was 290-300 HV, hardness of the weld material was 280 HV in the middle of the seam and 290 HV closer to the dilution zone (Fig. 5).

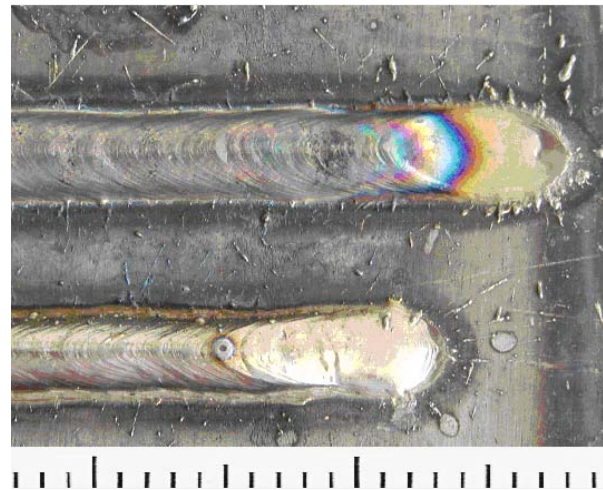


Fig. 1 The common view of seams when welding titanium alloy BT 3-1 by wire BT 1-0 in the medium of argon using alternating current, colors on the seam appeared due to the curtailment of argon supply to the uncongealed seam (mark size - 20 mm)

The application of filler metal BT 1-0 specifies high plasticity of the weld metal (BT 3-1 – $A = 12-14\%$); however, because of the lower strength of the seam (BT 3-1 – $R_m = 850-900$ MPa) the durability of welded joints is reduced. The application of filler metal BT 1-0 specifies high plasticity of the weld metal (BT 3-1 – $A = 12-14\%$); however, because of the lower strength of the seam (BT 3-1 – $R_m = 850-900$ MPa) the durability of welded joints is reduced. With single-pass welding by the melting electrode without preparation of edges the filler metal port forming the weld is insignificant, what decreases the influence of additives on chemical composition and, therefore, on mechanical properties of the seam (Fig. 6).

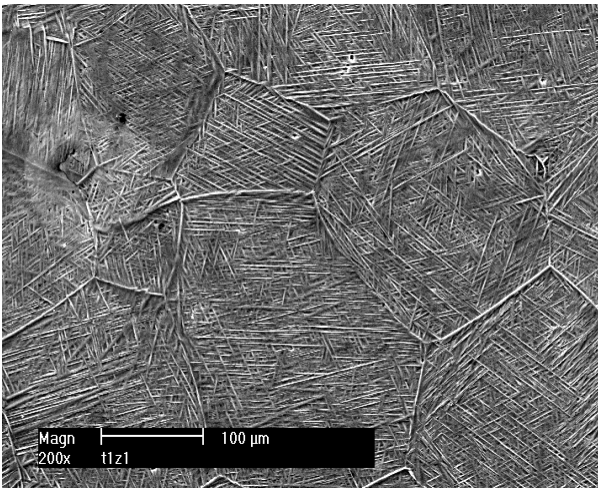


Fig. 2 Microstructure of titanium alloy BT 3-1

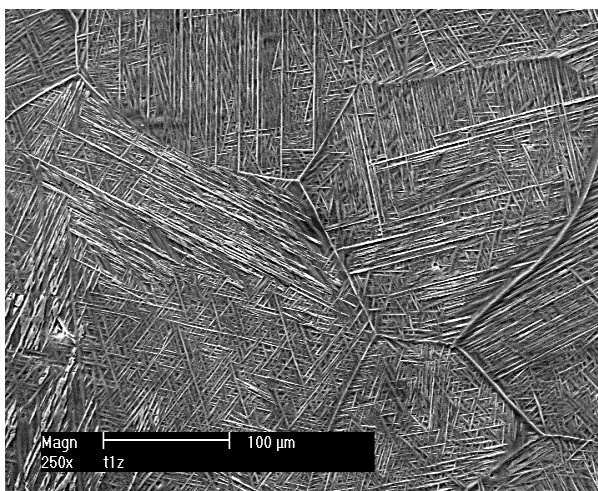


Fig. 3 Microstructure of weld material when welding the malleable alloy of titanium BT 3-1 by wire BT 1-0 in the medium of argon

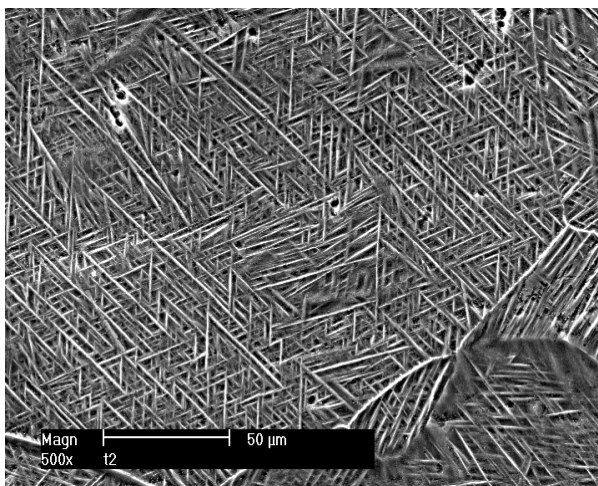


Fig. 4 Microstructure of dilution zone when welding the malleable alloy of titanium BT 3-1 by wire BT 1-0 in the medium of argon

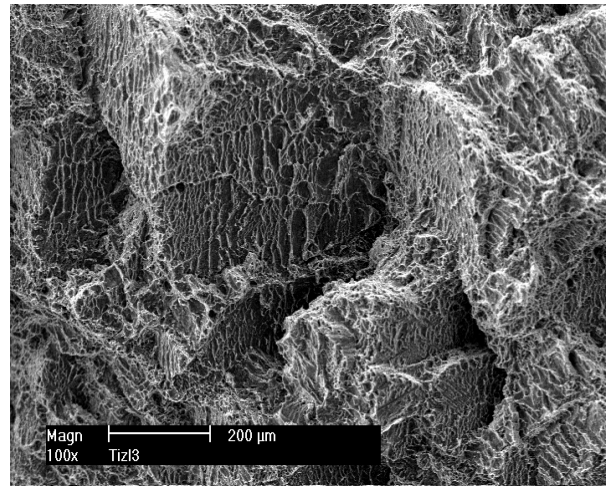


Fig. 5 Fractogram of seam destruction, obtained when welding the malleable alloy of titanium BT 3-1 by wire BT 1-0 in the medium of argon

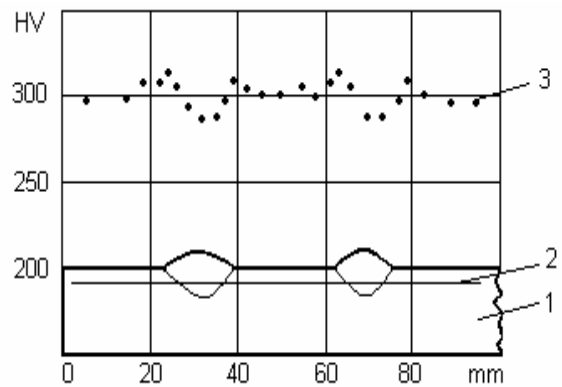


Fig. 6 Hardness of metal when welding wire BT 1-0 on the alloy of titanium BT 3-1 (1 - titanium alloy, 2 - line of the measurement of hardness, 3 - obtained values of the hardness)

4. Conclusions

1. It is established that in case of mechanized welding of the bead to the alloy of titanium BT 3-1 GOST 19807 using wire BT 1-0 GOST 19807 in the medium of argon, the metal of dilution zone has the structure of α' -martensite type phase without sharp passage from the base metal to the seam.

2. In case of automatic bead welding to the malleable alloy of titanium BT 3-1 using wire BT 1-0 in the medium of argon, the weld material has the structure of α' -martensite type phase with a small quantity of β -phase.

3. Maximum hardness after welding was observed in the dilution zone (320 HV), with the minimum in the middle of seam - 280 HV.

References

1. **Gurevich, S.M. and others.** Welding the High-Strength Titanium Alloys.-Moscow: Machine Building, 1975.-150p. (in Russian).
2. **Gorynin, I.V., Chechulin, B.B.** Titanium in Machine Building.-Moscow: Machine Building, 1990.-400p. (in Russian).

3. **Chechulin B.B. and others.** Titanium Alloys in Machine Building.-Leningrad: Machine Building, 1977.-248p. (in Russian).
4. ASM International. Metals Handbook. Welding, Brazing, and Soldering – USA, 2000, v. 6.-1299p.
5. Welding Titanium. TWI and the Titanium information Group, Granta Park, Great Abington, Cambridge, CB1 AL, UK, 1999.-34p.

I. Višniakas

METALO STRUKTŪROS GAUTOS, APVIRINANT TITANO DEFORMUOJAMĄ LYDINĮ, TYRIMAS

R e z i u m ė

Titano ir jo lydinių suvirinamumas daugiausia priklauso nuo jų fizikinių ir cheminių savybių. Svarbiausios iš šių savybių yra: aukštas titano aktyvumas esant padidintoms temperatūroms, padidintas grūdo augimas kaitinant ir trapių fazių susidarymo galimybė aušinant suvirintą jungtį. Azotas, deguonis ir ypač vandenilis dideliame koncentracijų diapozone sudaro su titanu kietus įterpimo tirpalus. Šios dujos žymiai sumažina metalo plastiškumą ir padidina jo kietumą bei stiprumą. Įterpimo priedai (dujos) skatina siūlių trapų irimą, didina jų polinkį šaltųjų plyšių susidarymui ir lėtam suiriumi. Mes atlikome siūlių metalografinius tyrimus, gautus apvirinant mechanizuotu būdu deformuojamąjį titano lydinį BT 3-1 GOST 19807 (Ti-6Al-2Cr-2,5Mo-Zr pagal CR ISO 15608) viela BT 1-0 GOST 19807 argono aplinkoje.

Nustatyta, kad didžiausi struktūros pasikeitimai, ir atitinkamai, savybių pasikeitimai įvyksta sulydymo srityje. Šios zonos dydis priklauso nuo šių pagrindinių faktorių: suvirinimo metodų ir režimų, lydinio cheminės sudėties, suvirinamų lapų storio, suvirinimo sąlygų. Sulydymo sritis yra svarbiausia, įvertinant titano lydinių suvirinamumą ir suvirintųjų jungčių darbingumą.

I. Vishniakas

STUDY OF METAL STRUCTURE WELDED ON THE TITANIUM MALLEABLE ALLOY

S u m m a r y

The weldability of titanium and its alloys depends on their physical and chemical properties. The most important of them are: high activity of titanium at elevated temperatures, significant tendency of grain growth at heating and the possibility of brittle phases forming during cooling of the welded joint. Nitrogen, oxygen and especially hydrogen in wide range of concentrations with titanium form interstitial solid solutions. These gases sharply decrease plasticity and considerably increase

hardness and strength of the metal. Interstitial impurities (gases) cause brittle failure of seams, increase their tendency towards cold cracking and delayed fracture. The metallographic examinations of the seams obtained by mechanized welding on the titanium malleable alloy BT 3-1 GOST 19807 (Ti-6Al-2Cr-2,5Mo-Zr by CR ISO 15608) by the wire BT 1-0 GOST 19807 in the medium of argon was carried out by us.

It is established that abrupt changes in the structure and, correspondingly, properties occur in the dilution zone. The size of this zone depends on the following basic factors: method and welding conditions, chemical composition of the alloy, thickness of the sheets to be welded, conditions for welding. Dilution zone appears to be determining for the estimation of weldability of titanium alloys and operation capacity of welded joints.

И. Вишнякас

ИССЛЕДОВАНИЕ СТРУКТУРЫ МЕТАЛЛА ПОЛУЧЕННОЙ ПРИ НАПЛАВКЕ НА ТИТАНОВЫЙ ДЕФОРМИРУЕМЫЙ СПЛАВ

Р е з ю м е

Свариваемость титана и его сплавов в своей основе зависит от их физико-химических свойств. Наиболее важными из этих свойств являются: высокая активность титана к газам атмосферы при повышенных температурах, значительная склонность к росту зерен при нагреве и возможность образования хрупких фаз при охлаждении сварного соединения. Азот, кислород и особенно водород в широком диапазоне концентраций образуют с титаном твердые растворы внедрения. Эти газы резко снижают пластичность и значительно повышают твердость и прочность металла. Примеси внедрения (газы) вызывают хрупкое разрушение швов, увеличивают их склонность к образованию холодных трещин и замедленному разрушению. Нами были проведены металлографические исследования швов, полученных при механизированной наплавке на титановый деформируемый сплав BT 3-1 ГОСТ 19807 (Ti-6Al-2Cr-2,5Mo-Zr по CR ISO 15608) проволокой BT 1-0 ГОСТ 19807 в среде аргона.

Установлено, что наиболее резкие изменения структуры и, соответственно, свойств происходят в зоне сплавления. Величина этой зоны зависит от следующих основных факторов: метода и режимов сварки, химического состава сплава, толщины свариваемых листов, условий сварки. Зона сплавления является определяющей при оценке свариваемости сплавов титана и работоспособности сварных соединений.

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