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Welding of a corrosion-resistant composite material based on VT14 titanium alloy obtained using an electron beam emitted into the atmosphere

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Abstract. The study investigates the possibility of inert gas arc welding of a double layer composite material on a titanium base with an anti-corrosive layer obtained by fused deposition of a powder mix containing tantalum and niobium over a titanium base using an electron beam emitted into the atmosphere. Butt welding and fillet welding options were tested with two types of edge preparation. Welds were subjected to a metallographic examination including a structural study and an analysis of the chemical and phase composition of the welds. A conclusion was made regarding the possibility of using welding for manufacturing of items from the investigated composite material.

1. Introduction

The surface layer of a titanium base may be alloyed with refractory and corrosion resistant elements, such as tantalum and niobium using an electron beam with high penetrability emitted into the atmosphere [1-4]. These alloying elements have high solubility in the alpha and beta- phases of titanium, thus forming substitutional solutions [5, 6]. Surface layers formed using the powder metallurgy method with an electron beam have corrosion resistance in numerous aggressive media exceeding the resistance of titanium and stainless steel by many times [1-3, 7, 8]. The alloyed layers, and the VT14 titanium alloy base on which they are fused deposited have a set of mechanical properties enabling industrial use of the obtained composite material. The alloyed layer with a thickness of about 2 mm has high adhesion to base and tensile strength. Due to the peculiarities of fused deposition, however, this method may be used for manufacturing of plate materials only. The essential question regarding use, therefore, is whether normal operations with plate materials, such as welding, expansion, rolling, can be performed with the composite material. In [9] the authors performed the welding of low alloyed uniform material. This work investigates the possibilities of arc welding of the obtained composite material with inert gases: argon and helium.

2. Materials and Methods

A layer of powder containing a mixture of alloying components and flux was placed on the surface of the titanium base of Russian grade VT14 alloy to prepare the source samples. The following powder composition was used: 30%Ta+9%Nb+23%Ti+28.5%CaF₂+9.5%LiF. The alloying components of the



source samples were fused deposited on an ELV-6 industrial electron accelerator, equipped with a device for electron beam emission into the atmosphere. The equipment was manufactured by the Budker Institute of Nuclear Physics, Novosibirsk [10, 11]. The energy of electrons in the beam was equal to 1.4 MeV. Powder mass density equal to 0.45 g/cm² was selected so as to make sure that a beam completely penetrated the layer of powder and ensured its uniform heating. The source samples had dimensions of 12.7x50x100 mm after fused deposition with an electron beam. Welding was performed along the sample's longer edge with a 10 mm strip cut off in advance in order to prevent possible decrease of coating thickness at the sample edge. Thus, the dimensions of samples before welding were equal to 12.7x40x100 mm.

Both double-sided and single-sided welding with a non-consumable electrode and an argon or helium-shielded arc was used. The side opposite to the arc was protected with a special hood with argon fed into it. Source workpieces were butt or fillet welded. Rods with a section of 2x2 mm cut on an EDM machine from coatings of samples made especially for this purpose were used as filler for welding the coating. The composition of rods was close to the composition of the coatings being welded (16 % Ta and 5 % Nb). Tantalum wire was used as an alternative filler. Filler made of VT1sv of Russian grade welding wire was used for welding on the base. Weld edge preparation options are shown in figure 1. Welding modes used during the experiment are listed in table 1. The weld shown in figure 1a may be used when there is no access from the coating side, e.g. for pipe welding. In such weld the coating is welded first followed by weld reinforcement by welding on the base using VT1sv wire as filler.

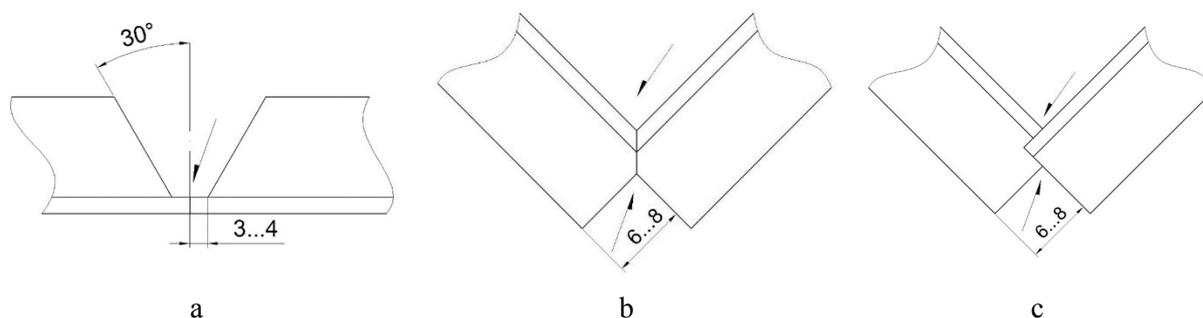


Figure 1. Weld edge preparation: a – single-sided butt weld, b – fillet weld with beveling, c – fillet tongue and groove weld.

Table 1. Welding parameters for VT14 titanium samples with a Ti-Ta-Nb coating.

Sample number	Weld configuration per figure 1	Filler wire in coating weld	Protective atmosphere for coating welding	Coating welding current, A
1	a	16Ta-5Nb-Ti	He	100
2	b	16Ta-5Nb-Ti	Ar	110
3	c	Ta	Ar	130

Metallographic studies were performed using a Carl Zeiss Axio Observer A1m optical microscope and a Carl Zeiss EVO 50 XVP scanning electron microscope. The chemical composition of the welded composites was determined using an X-ACT energy-dispersive micro X-ray analyser (Oxford Instruments).

The phase analysis of the welds on the coating was performed using an ARL X'TRA X-ray diffractometer. Diffraction patterns were obtained using CuK α_1/α_2 radiation.

3. Results and Discussion

The external appearance of the samples after welding is shown in figure 2. A visual examination proved that there were no macro defects in the welds and HAZ both in the coating and in the titanium base.

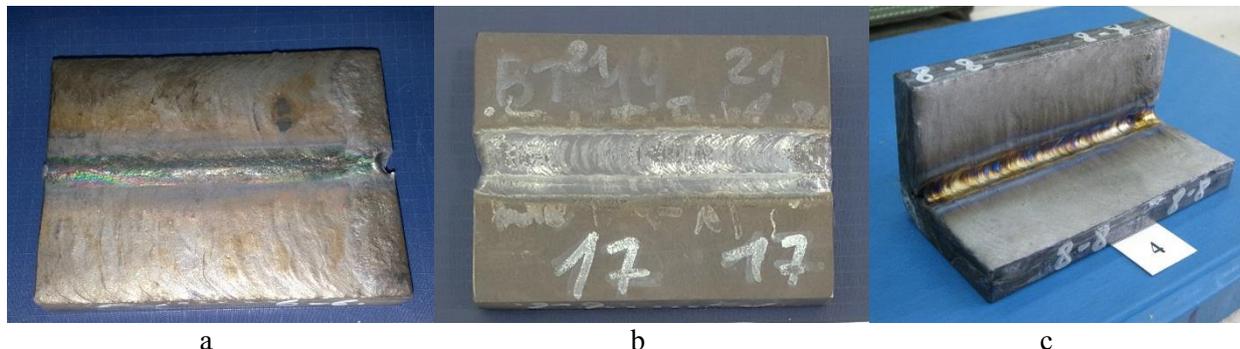


Figure 2. The external appearance of samples after welding: a – single-sided butt weld on the coating side; b – single-sided butt weld on the base metal side; c – fillet tongue and groove weld on the coating side.

The structure of the welds obtained using butt and fillet welding is presented in figures 3 and 4. The cross-section of the created samples does not contain such defects as fractures, but has a small number of pores (samples 1, 2) and insoluble particles of the alloying components (sample 3). Pores in sample 1 are mostly confined to the areas of titanium layer fusion (figure 4a). The maximum cross-section size of pores is $\sim 450 \mu\text{m}$. The pores in sample 2 are observed at the boundary of the weld and surface-welded coating (figure 4b). The pore size in this case does not exceed $200 \mu\text{m}$. It should be noted that pores found in the sample structure are individual and closed.

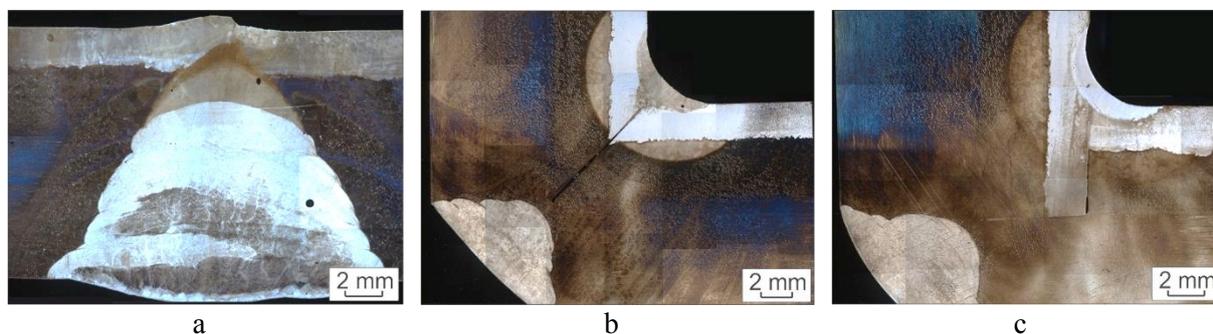


Figure 3. A panoramic view of samples: a – single-sided butt weld, b – fillet weld with beveling, c – fillet tongue and groove weld.

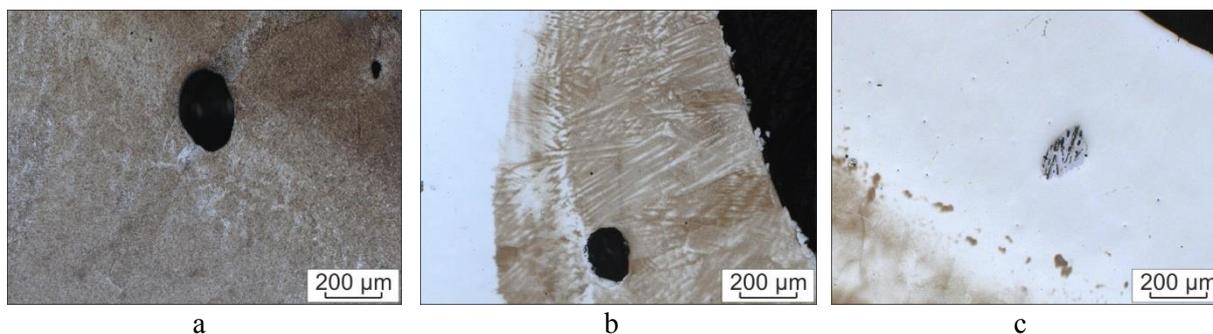


Figure 4. Weld defects: a – pores in sample 1; b - pores in sample 2; c – non-dissolved particles in sample 3.

The coating weld is in all cases exhibits a clear dendritic structure (figure 5a). The dendritic crystals mostly grow in the direction away from the molten pool towards the weld surface. With high magnifications, a martensite-structure typical for a majority of fused deposited titanium alloys is observed [2-4] (figure 5 b). The welds on the titanium base side are also characterized by a martensite-type structure, but the dispersion of plates is visually significantly lower than in the coating welds (figure 5c).

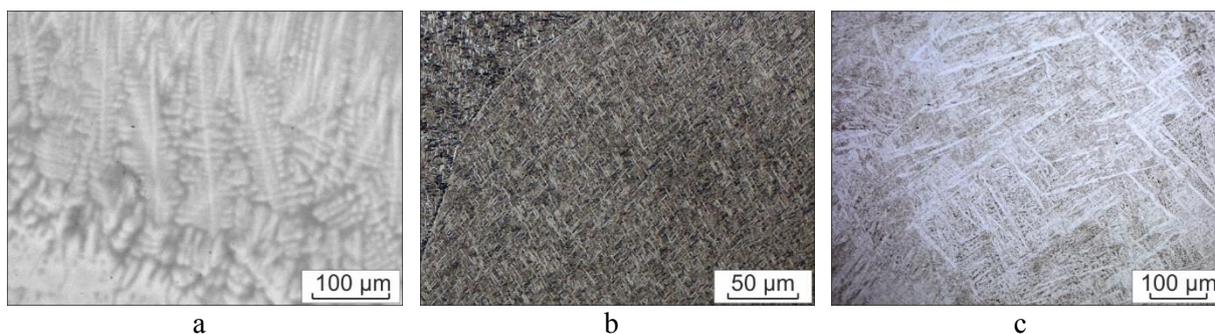


Figure 5. The structure of welds: a – dendritic structure in sample 3; b – martensite-type structure of the coating weld in sample 1; c – martensite-type structure of the titanium base of sample 1.

A chemical analysis of the weld was performed using the EDX method. The concentration of alloying elements for sample 1 was measured in the areas shown in figure 6. The analysis results are presented in table 2. The weld made with a filler wire from coating (spectrum 3) has a composition similar to the coating (table 2). Further filling with titanium results in a partial mixing of the layers and a reduction in the concentration of the alloying elements. The layers welded during the last pass consist mostly of titanium (spectrum 6).

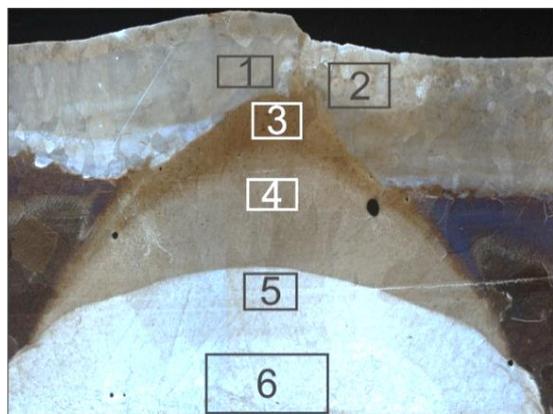


Table 2. Weld chemical compositions at areas of spectrum accumulation of sample 1.

Number of spectrum	Content, wt. %		
	Ta	Nb	Al
1	17,8	4,5	3,5
2	14,8	4,7	3,9
3	14,7	3,7	3,5
4	14,9		2
5	5,1		0,6
6			0,7

Figure 6. Weld chemical analysis: areas of spectrum accumulation of sample 1.

The EDX analysis results for the fillet welds are presented in table 3. The highest content of the alloying elements was recorded in the weld of sample 3. The tantalum and niobium concentration in it equals 47 wt.% and 2.9wt% respectively. The high tantalum content is explained by the use of tantalum wire for this sample as filler wire. The tantalum concentration in the weld of sample 2 is significantly lower than in sample 3 and equals 21.8 wt.%. The niobium content in the sample was 2.8 wt.%. A small amount of aluminum transferred from the titanium base to the coatings during electron beam fused deposition was also detected in all welds by EDX analysis.

Table 3. Chemical composition of the fillet welds.

Mode number	Chemical composition (Ti – the rest), wt %		
	Ta	Nb	Al
2	21,8	2,8	1,8
3	47	2,9	2,1

A structural X-ray analysis was performed in order to determine the phase composition of the coating welds. Sample 1 after butt welding was selected for the examination. The X-ray phase analysis identified the presence of titanium α - and β -phase peaks (figure 7). The diffraction pattern has the following features: a significant widening of the peaks, deviation of the relative peak intensity from the theoretical values, displacement of the peaks relative to the data in ICDD PDF-4+ database. Widening of the peaks may be explained by formation of a fine structure with a high level of microstresses and small size of coherent dispersion areas. On the other hand, wide peaks may be evidence of an emerging chemical composition gradient resulting in a variation of the primitive cell parameters of the formed solid solutions depending on the quantity of alloying elements in a local volume of the material. The deviation of the relative peak intensity from the theoretical values may occur as a result of formation of a texture [12-14] typical for the process of primary crystallization. The displacement of peaks relative to the database values serves as evidence of a change in primitive cell parameters. The parameter change is caused by formation of substitutional solid solutions and non-uniform cooling conditions.

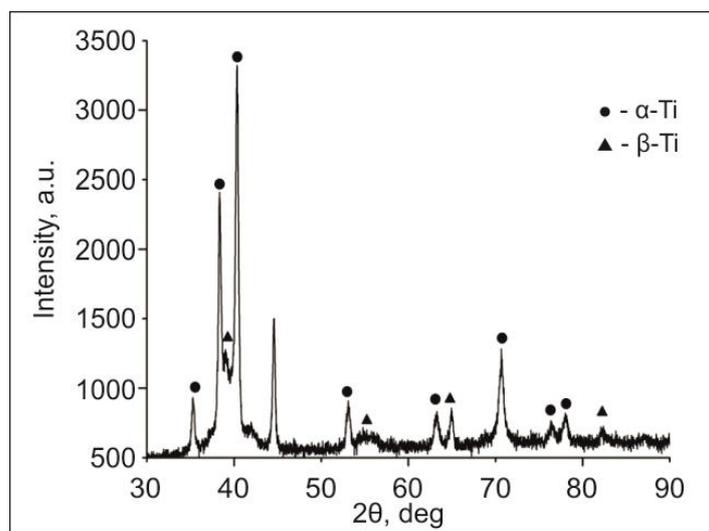


Figure 7. The X-ray pattern of the coating weld.

4. Conclusions

This study demonstrates the possibility of shielded-arc welding of titanium workpieces surface-alloyed by tantalum and niobium. The created welds have a uniform structure. There are no fractures, discontinuities or laminations observed in the weld structure. The detected defects such as pores and undissolved particles are individual and closed. It was established that welds mainly have a dendritic formation and martensite-type structure. The analysis of the X-ray patterns confirmed the presence of two phases: titanium α - and β -phases. The detected mismatch of integral intensities and the widening of peaks on the X-ray pattern prove that the weld contains texture and a fine structure with a high level of microstresses. The chemical analysis of the welds matches the analysis of coatings if the workpieces are welded with filler rod cut from the coating. The concentration of the alloying elements is significantly higher than at coating when samples are welded with tantalum wire.

Acknowledgments

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