

Ti₂AlNb-BASED INTERMETALLIC ALLOYS AND COMPOSITES

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Abstract. Optimization of the chemical composition of Ti₂AlNb-based alloy resulted in development of high-strength Ti-20.3Al-22.1Nb-1.2Zr-1.3V-0.9Mo-0.3Si (at.%) intermetallic with rather low density $\rho \approx 5.1 \text{ g/cm}^3$. Mechanical properties of the alloy were considerably improved due to formation of the homogeneous ultrafine-grained structure. The ultrafine-grained material exhibited both high strength and ductility at room temperature ($\sigma_{\text{UTS}}=1400 \text{ MPa}$; $\delta=25\%$) and superplastic behavior in the temperature range of 850-1000°C ($\delta_{\text{max}}=930\%$ at $T=900^\circ\text{C}$). The metal-intermetallic composites consisting of alternating layers of the orthorhombic intermetallic alloy and the commercial high-temperature titanium alloy were produced. The 3-layered composite had high strength and reasonable ductility both at room and elevated temperatures: $\sigma_{\text{UTS}}=1235 \text{ MPa}$ and $\delta=4\%$ at $T=20^\circ\text{C}$; $\sigma_{\text{UTS}}=875 \text{ MPa}$ and $\delta=21\%$ at $T=600^\circ\text{C}$.

Keywords: intermetallic Ti₂AlNb-based alloy, ultrafine-grained material, mechanical properties, metal/intermetallic composite.

1. Introduction

The progress in engineering, aerospace, and nuclear industries requires new structural materials that should possess a higher level of service properties as compared to the commonly used materials [1-7]. In this regard, titanium alloys and intermetallics based on titanium aluminides are of a great interest. Titanium alloys have relatively low density, sufficient ductility, and fracture toughness [1]. However, they have reasonable creep and oxidation resistance only at temperatures up to 500-550°C. Intermetallic alloys based on titanium aluminides are considered as promising materials for high-temperature applications [1-3]. They possess much better resistance to creep and burn than conventional titanium alloys, enabling operation at temperatures of 600-800°C. Intermetallics based on the ordered orthorhombic Ti₂AlNb-phase do not suffer from the very poor ductility and fracture toughness usually associated with titanium aluminides based on γ -TiAl and α_2 -Ti₃Al [2-7]. However, because of the high content of niobium, these intermetallic alloys are substantially heavier ($\rho > 5 \text{ g/cm}^3$) than other titanium aluminides and optimization of the alloy composition in order to decrease their density is an important issue. This task may be solved by substitution of some of niobium atoms with such alloying elements as molybdenum and vanadium, which are stronger β -stabilizers than niobium [8-10]. Besides, for commercial application of Ti₂AlNb-based alloys the problems of workability improvement and decreasing the temperatures of secondary processing should be also overcome. It was recently shown that grain refinement provides substantial increase in ductility and decrease in the temperatures of superplasticity [11-14]. Thus, grain refinement in Ti₂AlNb-based alloys to submicron or even nanometer level seems to be an effective way for their workability improvement.

Another way to obtain material, which combines both high-temperature strength and reasonable ductility, is production of composites consisting of alternating layers of intermetallic and commercial high-temperature titanium alloy. The technology of production of composites out of dissimilar materials was recently developed at the Institute for Metals Superplasticity Problems [14-16]. It includes preliminary microstructure refinement in the preforms of the composite components, their solid state bonding, subsequent heat treatment, and secondary processing. Formation of the ultrafine-grained (UFG) microstructure in the preforms provides the closeness of mechanical properties in dissimilar materials and, thus, uniform distribution of strains within the composite layers during solid state bonding and subsequent processing. Preliminary microstructure refinement in the preforms also makes possible to decrease the temperature of the solid state bonding and increase the quality of the joint [12].

In the present work, both research targets were successfully realized to improve mechanical properties of the Ti₂AlNb-based alloy. The optimized composition of Ti₂AlNb-based alloy was developed and the composites consisting of alternating layers of the orthorhombic intermetallic alloy and a two-phase titanium alloy were produced.

2. Experimental

The ingot with the nominal composition of Ti-20.3Al-22.1Nb-1.2Zr-1.3V-0.9Mo-0.3Si (at.%) was used as a starting material. Multi-step isothermal forging at temperatures below the β -transus and intermediate annealings were used for microstructure refinement. The processing details are given elsewhere [13,14].

Microstructure analysis was performed using Axiovert 100A and Olympus GX51 optical microscopes and JEM-2000EX transmission electron microscope operating at an accelerating voltage of 200 kV.

Tensile properties of flat electropolished samples were studied at temperatures ranging from 20°C to 1000°C and initial strain rates $\dot{\epsilon}=4.2\times 10^{-4}$ - 8.3×10^{-2} s⁻¹ using an Instron testing machine. The gauge size of the UFG samples cut from forging pancakes was 10×3×2 mm³ while that for composite samples was 20×5×(2-4.5) mm³ depending on the thickness of the rolled composite plates. From the tensile tests, the elongation to rupture, δ , the ultimate tensile strength, σ_{UTS} , the yield strength, σ_Y , the steady state flow stress corresponding to elongation of 50%, σ_{50} , were determined.

Sheet rolling of the Ti₂AlNb-based alloy in the UFG condition was performed at T=850-950°C using a duo rolling mill with 300 mm-diameter rolls. The rolling details are given in [13,14].

In order to produce the sheet composite, the preforms out of the Ti₂AlNb-based intermetallic alloy and the commercial titanium alloy Ti-12Al-0.7Sn-2.17Zr-2Mo-0.26W-0.34Si (at.%), designated in Russia as VT25U, were first solid state bonded at 900-950°C in vacuum and then jointly hot rolled with $\dot{\epsilon}\approx 10^{-1}$ s⁻¹ and $\epsilon=10\%$ per pass. Suggested technique was used to obtain 2-layered composite plates out of VT25U/Ti₂AlNb-based alloy with approximate sizes 150×50×2 mm³ and 3-layered composite plates out of VT25U/Ti₂AlNb-based alloy/VT25U with approximate sizes 150×50×4.5 mm³.

3. Results and Discussion

The so-called (O-Ti₂AlNb+B2-Ti) intermetallic alloys, which contain 20÷22 at.% of aluminium and 25÷27 at.% of niobium, have the best balance of mechanical properties among Ti₂AlNb-based intermetallic alloys and their density is $\rho\approx 5.3$ - 5.5 g/cm³ [8,17-19]. In order to decrease the density of Ti₂AlNb-based intermetallic alloys it makes sense to decrease the niobium content by its substitution with the stronger β -stabilizing alloying elements. According to literature data [8], an addition of 1 at.% of molybdenum or vanadium corresponds to the replacement of 4.25 or 1.58 at.% of niobium, respectively. Along with molybdenum, the

optimized alloy composition should also contain zirconium and silicon in order to compensate for the loss in yield stress and creep resistance due to reduced niobium content [9]. Optimization of the chemical composition of the (O-Ti₂AlNb+B2-Ti) intermetallic alloy resulted in development of the Ti-20.3Al-22.1Nb-1.2Zr-1.3V-0.9Mo-0.3Si alloy with a lower density $\rho \approx 5.1 \text{ g/cm}^3$.

Microstructure of the ingot consisted of equiaxed coarse grains of the Ti₂AlNb-phase with sizes ranging from 500 to 3000 μm and precipitations of the second β /B2-phase particles (Fig. 1a). After multi-step hot forging, a homogeneous UFG microstructure with the average grain size of $d \approx 0.3 \mu\text{m}$ was formed (Fig. 1b).

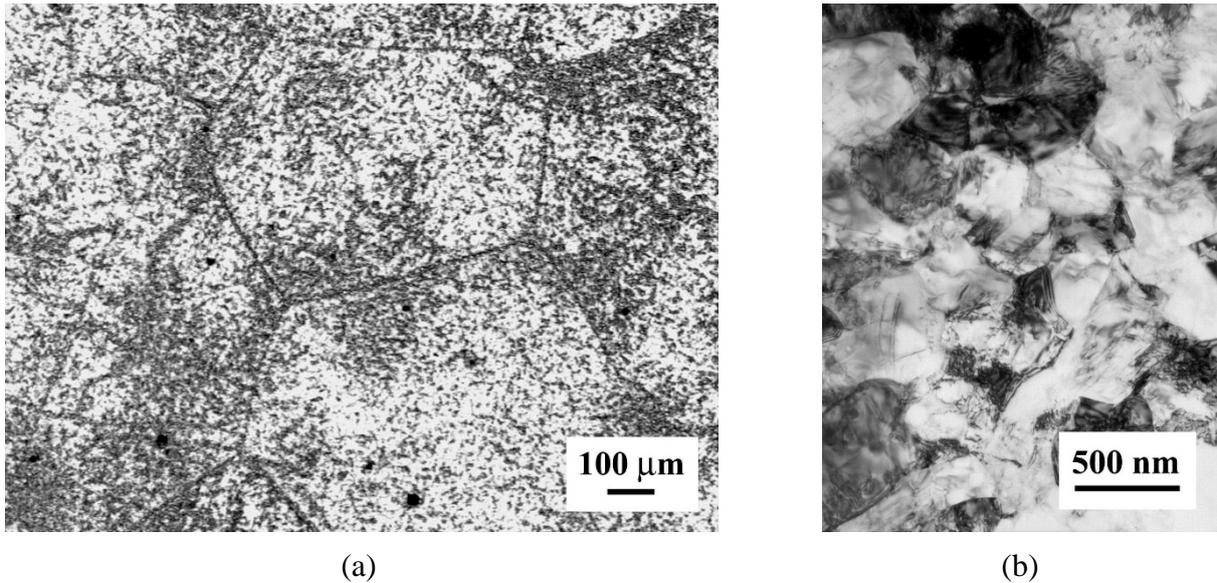


Fig. 1. Typical microstructures of the Ti₂AlNb-based intermetallic alloy: (a) the as-cast condition and (b) the UFG condition.

The UFG alloy showed both high strength and excellent ductility at room temperature. The ultimate strength reached $\sigma_{\text{UTS}} = 1400 \text{ MPa}$ and elongations up to $\delta = 25\%$ were obtained.

The intermetallic alloy exhibited superplastic behavior in the temperature range of $T = 850\text{--}1000^\circ\text{C}$ and at strain rates $\dot{\epsilon} = 4.2 \times 10^{-4}\text{--}2.0 \times 10^{-2} \text{ s}^{-1}$ (Fig. 2). At $\dot{\epsilon} = 8.3 \times 10^{-4} \text{ s}^{-1}$, elongation first increased with increasing the testing temperature, reached a maximum $\delta = 755\%$ at $T = 900^\circ\text{C}$ and then decreased (Fig. 2a). The steady state flow stress decreased sharply from 366 MPa to 54 MPa when the temperature increased from 800°C to 900°C , while only a slight decrease in σ_{50} was observed in the temperature range of $900\text{--}1000^\circ\text{C}$ (Fig. 2a). At $T = 900^\circ\text{C}$, elongation of the UFG alloy increased with increasing the strain rate from $4.2 \times 10^{-4} \text{ s}^{-1}$ to $4.2 \times 10^{-3} \text{ s}^{-1}$, reached a maximum $\delta = 930\%$ at $\dot{\epsilon} = 4.2 \times 10^{-3} \text{ s}^{-1}$ and then decreased (Fig. 2b). But even at a rather high strain rate $\dot{\epsilon} = 8.3 \times 10^{-2} \text{ s}^{-1}$ the elongation was as high as $\delta \approx 120\%$. The steady state flow stress at 900°C increased from 50 MPa to 264 MPa with increasing the strain rate from $4.2 \times 10^{-4} \text{ s}^{-1}$ to $8.3 \times 10^{-2} \text{ s}^{-1}$ (Fig. 2b).

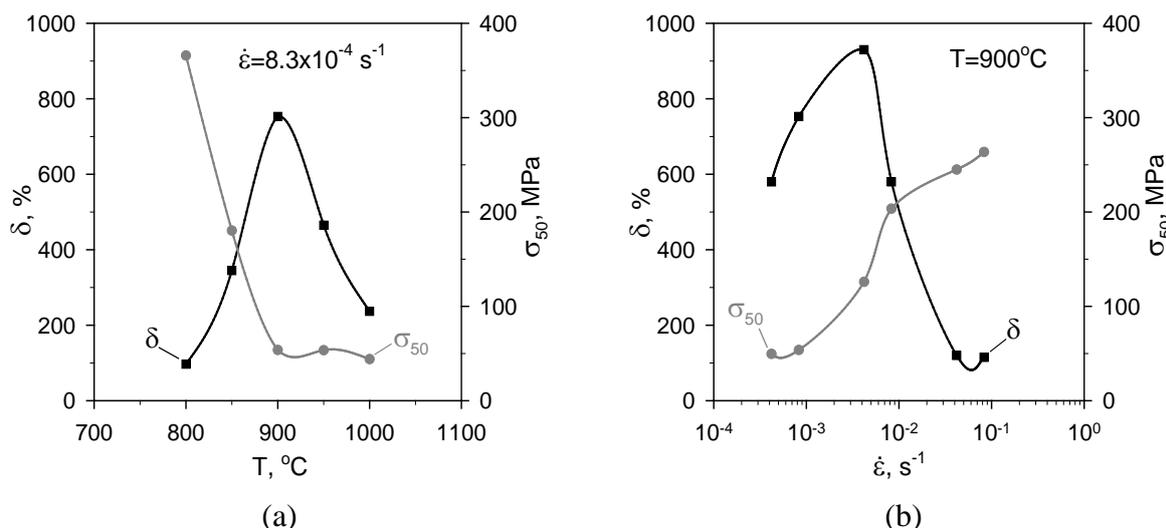


Fig. 2. (a) The temperature dependencies and (b) the strain rate dependencies of elongation, δ , and steady state flow stress, σ_{50} , of the UFG alloy.

In order to define the processing window for sheet rolling, mechanical behavior of the UFG material was studied in the temperature range of 700-1000°C and at a typical rolling strain rate $\dot{\epsilon} \approx 10^{-1} \text{ s}^{-1}$. The yield strength decreased from 515 MPa to 180 MPa with increasing the testing temperature from 800°C to 900°C (Fig. 3). The total elongation sharply increased from 38% to 120% in the temperature range of 800-850°C (Fig. 3) suggesting that sheet rolling of the UFG alloy should be performed at temperatures above 800°C. On the other hand, sheet rolling should be performed in the temperature range of thermal stability of microstructure, in order to avoid substantial grain growth and a decrease in ductility during hot rolling. As it was shown earlier [13], microstructure was quite stable against grain growth in the three-phase ($\text{Ti}_2\text{AlNb} + \beta/\text{B}2 + \alpha_2$) region, i.e. below 1000°C. Reasoning from this, the temperature interval of sheet rolling of the Ti₂AlNb-based intermetallic alloy should be chosen within 850-950°C. Taking into account the temperature transients during hot rolling [20-21], the two-step sheet rolling technique for the UFG intermetallic alloy was developed. In the case of relatively thick preforms ($h > 10 \text{ mm}$), conventional bare rolling may be used, while for thin preforms ($h < 5 \text{ mm}$) the pack rolling should be performed.

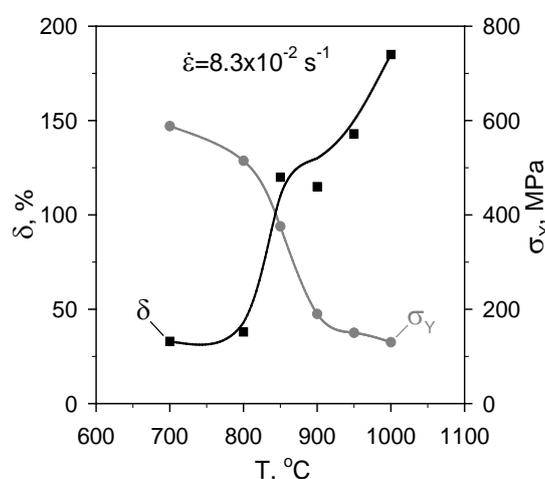


Fig. 3. The temperature dependencies of elongation, δ , and yield strength, σ_Y , of the UFG alloy.

The UFG Ti_2AlNb -based alloy was used for production of the composite plates which consisted of alternating layers of the intermetallic alloy and the commercial high-temperature titanium alloy VT25U with a microcrystalline structure ($d=5-10 \mu m$). The smaller grain size in the intermetallic alloy provided the closeness of the temperature and strain rate intervals of superplasticity for both alloys [12-14] and made possible to perform their solid state bonding and subsequent hot rolling at 900-950°C. The microstructure of the bonding zone is shown in Fig. 4 and mechanical properties of multilayer composites are given in Table 1.

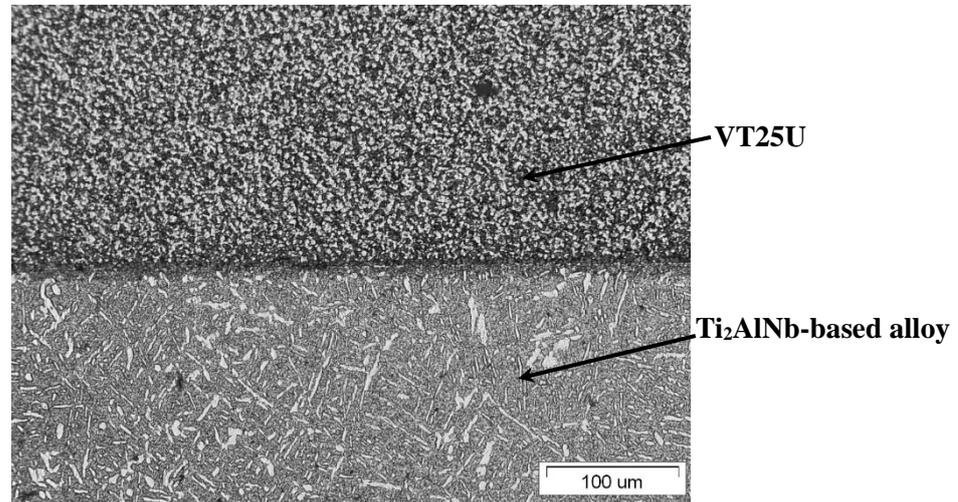


Fig. 4. Microstructure of the VT25U/ Ti_2AlNb -based alloy composite near the bonding zone.

Table 1. Mechanical properties of the metal-intermetallic composites.

T, °C	2-layered composite VT25U/ Ti_2AlNb -based alloy		3-layered composite VT25U/ Ti_2AlNb -based alloy/VT25U	
	σ_{UTS} , MPa	δ , %	σ_{UTS} , MPa	δ , %
20	1210	7	1235	4
600	835	12	875	21
700	610	18	645	26

The composites demonstrated high strength and reasonable ductility both at room and elevated temperatures. At 600-700°C, the ultimate strength and elongations of the 3-layered composite were higher than those of the 2-layered composite. This may be due to the favorable effect of titanium layers having a higher fracture toughness. As seen in Fig. 5, the cracks were initiated on the interlayer surfaces of the composite and grew rapidly in the intermetallic layer, while ductile titanium layers impeded the crack growth in the composite material. Reasoning from this, one may suggest that the increase of the number of layers would result in further improvement in mechanical properties of the metal-intermetallic composites.

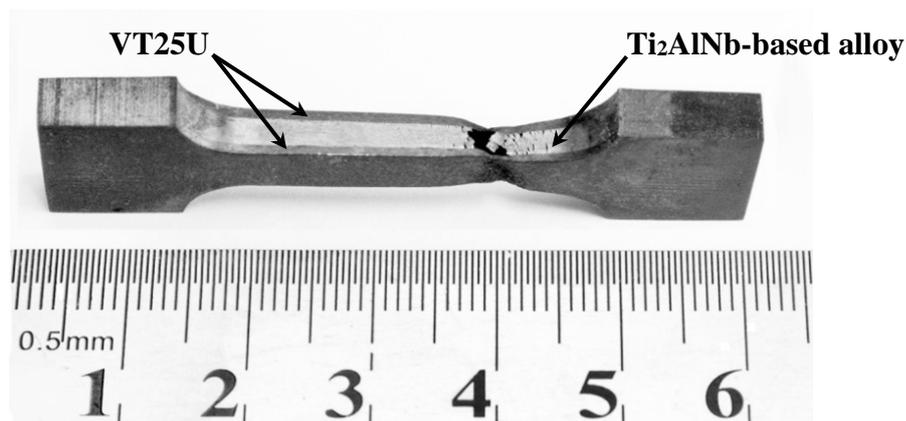


Fig. 5. The photograph image of the 3-layered VT25U/Ti₂AlNb-based alloy/VT25U composite tensile strained at 700°C. The test was interrupted before the failure.

4. Conclusions

The chemical composition of the Ti₂AlNb-based intermetallic alloy was optimized. The Ti-20.3Al-22.1Nb-1.2Zr-1.3V-0.9Mo-0.3Si (at.%) alloy had rather low density ($\rho \approx 5.1 \text{ g/cm}^3$) and excellent tensile mechanical properties. At room temperature, the alloy with a homogeneous UFG microstructure ($d \approx 0.3 \text{ }\mu\text{m}$) exhibited the ultimate strength $\sigma_{\text{UTS}} = 1400 \text{ MPa}$ and elongation $\delta = 25\%$. The UFG intermetallic alloy also demonstrated superplastic behavior at temperatures $T = 850\text{--}1000^\circ\text{C}$ and strain rates $\dot{\epsilon} = 4.2 \times 10^{-4}\text{--}2.0 \times 10^{-2} \text{ s}^{-1}$. Maximum elongation $\delta = 930\%$ was obtained at $T = 900^\circ\text{C}$ and a strain rate $\dot{\epsilon} = 4.2 \times 10^{-3} \text{ s}^{-1}$.

Composites consisting of alternating layers of the Ti₂AlNb-based intermetallic alloy and the commercial high-temperature titanium alloy were produced by combination of solid state bonding and hot rolling. Metal-intermetallic composites exhibited improved strength and reasonable ductility both at room and elevated temperatures. Particularly, the 3-layered VT25U/Ti₂AlNb-based alloy/VT25U composite had the ultimate tensile strength $\sigma_{\text{UTS}} = 1235 \text{ MPa}$ and elongation $\delta = 4\%$ at room temperature and $\sigma_{\text{UTS}} = 875 \text{ MPa}$ and $\delta = 21\%$ at $T = 600^\circ\text{C}$.

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