29th Congress of the International Council
of the Aeronautical Sciences
St. Petersburg, Russia; September 7-12, 2014

LOW-COST TITANIUM ALLOYS FOR TITANIUM-POLYMER LAYERED COMPOSITES

Pavel Panin*, Nadezhda Nochovnaya*, Dmitry Kablov*, Evgeny Alexeev*
***Federal State Unitary Enterprise "All-Russian Scientific Research Institute of Aviation Materials" (VIAM), 17 Radio st., 105005 Moscow, Russia**

Keywords: *low-cost titanium alloys, titanium-polymer laminates, corrosion resistance*

Abstract

Two pilot low-cost near-alpha (Ti–Fe–Zr–O–N) and alpha+beta (Ti–Al–V–Fe) alloys have been developed specially for titanium-polymer layered composites, which allow a 30 percent weight reduction in comparison to that of Al-based alloys. The new alloys are doped with REM and possess an increased contact corrosion resistance.

1 Introduction

When working in the aerospace area one should always bare in mind that new generation aircrafts as well as jet engines require advanced materials together with appropriate cost efficiency [1, 2]. All new structural materials are aimed at specific properties improvement. It should be noted hereto that titanium alloys possess an outstanding property-to-density ratio, but up to nowadays almost all possibilities of weight reduction for conventional titanium alloys have been exhausted.

Thus, a new class of materials is being rapidly developed – the so called titanium-polymer layered composite materials (or simply laminates). These composites are based on sheet semi-finished products of titanium alloys which are in contact with flat prepregs of carbon-filled plastic. Such a construction gives the opportunity to obtain up to 30 percent weight reduction in comparison to bulk aluminum-based alloys constructions. The use of titanium alloys instead of aluminum ones results in a considerable reliability increase due to the fact that titanium alloys almost lack corrosion-promoted damage. But still there exists a problem of contact corrosion resistance and a detailed research is strongly necessary in this particular field.

The present research project involves the development of new low-cost titanium alloys which would possess a desired contact corrosion resistance together with appropriate mechanical properties and cost efficiency.

2 Experimental details

Several pilot compositions of low-cost titanium alloys have been chosen for investigation (see table 1).

Table 1. Nominal chemical composition of pilot low-cost titanium alloys, [wt.%]

No	Al	V	Fe	Zr	O, N	Gd	Ti	Phase
1	2.0	–	1.2	1.0	(B)	–	bal	$\alpha(+\beta)$
2	–	–	$\Sigma=2.5$		0.3	–	bal	$\alpha(+\beta)$
3	–	–	$\Sigma=2.2$		0.3	0.3	bal	$\alpha(+\beta)$
4	4.4	$\Sigma=3.5$		–	–	–	bal	$\alpha+\beta$
5	4.3	$\Sigma=3.2$		–	–	0.3	bal	$\alpha+\beta$
6	4.5	$\Sigma=3.0$		–	–	0.5	bal	$\alpha+\beta$

Experimental ingots of ~30 kg wt. were melted with the use of consumable electrodes in the ALD VAR L200 vacuum-arc furnace. A very good chemical homogeneity of ingots was provided by means of threefold remelting.

The structure analysis was accomplished with the help of Zeiss AxioObserver optical microscope (bright field, dark field). For XRD patterns the Rigaku D\MAX diffractometer was used. Mechanical tests at room temperature were carried out on the Zwick machine.

Simulation of phase composition and properties in dependence on chemical composition of pilot alloys was held by means of JMatPro software (Sente Software, UK).

3 Results and discussion

The ‘low-cost alloy’ conception is based on the choice of particular alloying elements which would possess relatively low cost and/or be part of the most affordable master alloys. The focus on these requirements gives the opportunity to reduce the cost of a production process and therefore to reduce the net price of semi-finished products and finished articles without a significant loss in mechanical and service properties.

The group of low-cost titanium alloys includes low-doped alloys which do not contain expensive and/or scarce elements (Mo, Ta, Zr, Nb, W, etc.) and are based on relatively cheap commercially pure components (Al, Fe, Cu, etc.) [2]. When preparing charge for such alloys one can easily use the so called ‘natural master alloys’ – ferrotitanium and ferrovanadium. The low-cost titanium alloys also possess one more valuable advantage: the opportunity to involve metal scrap and waste products in the melting process.

However, the low level and instability of properties should be considered to be the most significant drawbacks of the discussed group of alloys, that being the reason for only ‘land facilities’ application thereof (medical implants, automotive items, and various decorative articles). Due to the recent development of metal-polymer composite materials the low-cost titanium alloys have acquired challenging prospects of being applied as sheet materials in multilayered titanium-polymer laminates for aviation and aerospace purpose.

Since the beginning of 2000s the research in the field of low-doped titanium alloys has been accelerated in VIAM, and in 2004 there was acquired the patent “Titanium-based alloy and article thereof” [3]. The proposed new low-cost titanium alloy contains iron, nitrogen, and oxygen as main alloying element; the alloy also contains a small amount of molybdenum for strengthening: Ti – balance, Fe=0.6…1.0, Mo=0.3…0.6, O=0.3…0.4, N=0.04…0.05 (wt.%). The alloy possesses medium strength (UTS=800…890 MPa), good ductility (EL=18.4…26.8 %), and increased impact toughness (KCU=520…560 kJ/m^2). This alloy is recommended for medical application due to its enhanced biocompatibility and lack of toxic elements (e.g., vanadium). But poor workability at room temperature proved to be one of the most significant drawbacks of the alloy – this fact left no opportunities to produce sheet semi-finished products thereof. The strength level also occurred to be insufficient for aviation purposes.

Up to the beginning of 2014 one can single out the following low-cost titanium alloys which have found practical application in different fields of engineering (see. table 2).

Table 2. Commercial low-cost titanium alloys (actualized 2014)

Year	Compos., [wt.%]	Commerc. name	Developer (country)	Ref.
1999	Ti-4Al-2.5V-1.5Fe-0.25O	–	TIMET Corp. (US)	[4]
2001	Ti-5Al-5V-5Mo-3Cr-0.5Fe;	Ti-5553	VSMPO-AVISMA (Russia)	[5, 6]
2006	Ti-3Al-5V-5Mo-3Cr-0.5Fe	Ti-3553		[7, 8]
2003	Ti-1Fe-0.35O-0.01N; Ti-1Fe-0.30O-0.04N	Super-TIX800 Super-TIX800N	Nippon Steel Corp. (Japan)	[9]
2004	Ti-6Al-0.5…4.0Fe-0.5N-0.2O (+0.5 wt.% REM)	–	Daido Steel Co. (Japan)	[10]
2004	Ti-0.8Fe-0.45Mo-0.35O-0.045N	–	VIAM (Russia)	[3]
2005	Ti-6Al-1.8Fe-0.1Si	Ti-62S	TIMET Corp. (US)	–
2007	Ti-1Al-0.5Si-0.3Nb	–	Kobe Steel Ltd. (Japan)	[11]
2007	Ti-1Cu-0.5Nb	–	Nippon Steel Corp. (Japan)	[12]
2007	Ti-7.5Al-1V-2Mo-2Cr-0.5Fe	–	MMM (US, China)	–

2009	Ti-5Al-1Sn-1Fe-1Cr	Ti-5111	Baoji Titanium Ind. Co. (China)	–
2012	Ti-4Al-0.1O-0.1Hf-V,Mo,Cr,Fe	–	Messier-Dowty SA (France)	–
2012	Ti-6.5Al-1.7V-1.7Mo-0.4Si-0.15Fe-0.2O-0.03C	–	TIMET Corp. (US)	[13]

In the present work the alloying composition of near-alpha alloys has been chosen in compliance with traditional regulations valid for this class of alloys: it is necessary to provide both stable homogeneous structure (>95 vol.% α-phase, up to 5 vol.% β-phase) and increased strength due to neutral strengthening elements.

The developed near-alpha low-doped alloy contains small amounts (up to 1.2 wt.%) of eutectoid-stabilizing element (Fe) and neutral strengthening element (Zr). The alloy also contains non-typical α-stabilizing elements – oxygen and nitrogen, – the use of which instead of an ordinary aluminum gave the opportunity to provide both effective alpha phase stabilization and significant solution hardening effect. In its turn, doping with interstitial elements (primarily boron, nitrogen and/or carbon, and rarely – oxygen) results in a double effect – both solution and precipitation strengthening due to boride, carbide and oxide particles [14–17]. Microalloying with gadolinium provided effective modification of coarse lamellar cast structure.

The two-phase α+β alloys possess a ‘classical’ alloying composition Ti–Al–V–Fe: α-stabilizer – aluminum, isomorphic β-stabilizer – vanadium, low-cost eutectoid-stabilizer – iron, and additional REM – gadolinium. The annealed pilot alloy Ti-4.3Al-3.2(V+Fe)-0.3Gd contains about 10 percent of equilibrium beta phase. Besides that the pilot alloy composition provides a significant technological advantage by giving an opportunity to use a wide range of charge materials including affordable ferrotitanium and ferrovanadium.

Experimental ingots of the pilot alloys were subjected to thermomechanical treatment by means of upsetting at β-area temperatures, and as a result wrought semi-finished products were obtained wherein the total amount of deformation was ~80 percent. The mechanical characteristics of such semis are shown in table 3.

Table 3. Mechanical properties of the pilot alloys (wrought semis)

Alloy composition, [wt.%]	UTS (20°C), [MPa]	KCU, [kJ/m^2]
Ti-2.2(Fe+Zr)-O-N (+Gd)	760	1055
Ti-4.3Al-3.2(V+Fe) (+Gd)	970	616

Tests on corrosion resistance were carried out on samples of pilot alloys being in contact with carbon-filled plastic. The results of the tests have shown no degradation traces on the metal surface.

4 Summary and further research

Thus, the two pilot low-cost titanium alloys have been developed: near-alpha alloy Ti-2…2.5(Fe+Zr)-O-N, and α+β alloy Ti-4…5Al-V-Fe. Both alloys are doped with REM (Gd) which resulted in strength and contact corrosion resistance increase in comparison to those of Gd-free alloys.

Further research in this field will be focused on thermomechanical treatment development in order to obtain thin sheet semi-finished products (<0.8 mm) which may find application in layered metal-polymer composites. Also a new low-modulus titanium-base alloy is needed specially for fastening elements for assembling the parts of titanium-polymer laminates.

Acknowledgements

The authors are grateful to the management of the All-Russian Scientific Research Institute of Aviation Materials (FSUE ‘VIAM’) and to all staff of the ‘Titanium alloys’ Department of VIAM.

References

[1] Boyer R R, Williams J C. Developments in research and applications in the titanium industry in the USA. *Proc. of 12th World Conf. on Titanium*, Vol. I, pp 10–19, 2011.

[2] Niinomi M. Recent trends in titanium research and development in Japan. *Proc. 12th World Conf. on Titanium*, Vol. I, pp 30–37, 2011.

[3] Pat. RU 2222627.

[4] Pat. US 5980655.

[5] Pat. RU 2169204.

[6] Pat. EP 1882752.

[7] Pat. RU 2169782.

[8] Pat. US 6632396.

[9] Pat. EP 2508643.

[10] Pat. JP 2004010963.

[11] Yashiki T. Development of a high temperature oxidation-resistant titanium alloy for exhaust systems of motorcycles and automobiles. *Proc. 11th World Conf. on Titanium*, Vol. II, pp 1387–1390, 2007.

[12] Otsuka H *et al.* Formability of newly developed high-performance titanium alloys for automotive exhaust systems. *Proc. 11th World Conf. on Titanium*, Vol. I, pp 251–254, 2007.

[13] App. US 2012/0107132.

[14] Conrad H. Effect of interstitial solutes on the strength and ductility of titanium. *Progress in Mat. Sci.*, Vol. 26(2–4), pp 123–403, 1981.

[15] Zhu J *et al.* Influence of boron addition on microstructure and mechanical properties of dental cast titanium alloys. *Mat. Sci. & Eng.: A*, Vol. 339(1–2), pp 53–62, 2003.

[16] Ando T *et al.* Precipitation of fine beta-phase in high nitrogen titanium alloy. *Proc. 11th World Conf. on Titanium*, Vol. I, pp 447–450, 2007.

[17] Koike M *et al.* Evaluation of cast Ti–Fe–O–N alloys for dental applications. *Mat. Sci. & Eng.: C*, Vol. 25(3), pp 349–356, 2005.

Contact Author E-mail Address

Corresponding author:
Pavel V. Panin, cand. of tech. sci., associate prof., Senior research scientist of “Titanium alloys” department, Federal State Unitary Enterprise “All-Russian Scientific Research Institute of Aviation Materials” (VIAM), Moscow, Russia.
E-mail: PaninPaV@yandex.ru

Copyright Statement