HEAT-RESISTANT BRAZING FILLER METALS FOR JOINING TITANIUM ALUMINIDE AND TITANIUM ALLOYS

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Abstract

Titanium alloys and titanium aluminides are being considered as key materials for the manufacture of lightweight compressors and turbines in modern aircraft and rocket engines. The joining technology that provides reliable work above 930°F (500°C) is needed to fabricate functional turbine components. Only then, the full high-temperature strength capabilities of TiAl alloys and titanium matrix composites can be exploited.

Two filler metals were tested for brazing heat-resistant joints at 2156-2190°F (1180-1200°C): TiBraze®1200 (Ni-27Ti-10Al) and TiBraze®375 (Ti-37.5Zr-15Cu-10Ni) in the form of transfer tape. Microstructure and shear strength of the brazed joints were studied at 1000, 1200, and 1470°F (540-800°C). Brazing at the temperature substantially above the liquidus of the filler metals resulted in a noticeable gain of both the high temperature and room temperature strengths. Joints of hot-pressed titanium aluminide brazed by Ti-37.5Zr-15Cu-10Ni filler metal exhibited shear strength at 1470°F (800°C) as high as 41.6-47.3 ksi (287-326 MPa) and 63-68 ksi (435-469 MPa) at 1200°F (650°C).

Some other methods for improving hot strength of titanium-based alloys are also discussed, particularly: (a) application of composite filler metals and (b) pre-coating of surfaces to be brazed to prevent early oxidation and promote wetting.

1. Introduction

Over 100 brazing filler metals were developed and tested for the last 50 years in response to the industrial needs in joining titanium alloys in the lightweight rocket and aircrafts structures. Main goals of these efforts were to reach and improve strength and corrosion resistance of brazed joints both titanium-to-titanium and titanium-to-dissimilar metals.

Despite of a number of tested filler metal compositions, only a few of them were accepted for serial production in the aerospace industry, and besides, there are still some problems related to strength and reliability of brazed joints. Indeed, hot strength, creep, and fatigue resistance of titanium brazed joints are not yet studied completely, - and we cannot name a copper-free brazing alloy which may response to requirements of high-temperature operation above 1112°F (600˚C) [1].

In recent years, there has been a successful development of γ-TiAl and NiAl alloys for gas turbine applications. These materials are attractive because of their low density, about half of that of nickel based superalloys and 10% less than Ti based alloys. Gamma TiAl alloys have found use in a wide range of components including compressor rotor blades and stator vanes, low-pressure turbine blades, combustor casings, and exhaust components. Some of these units, for example, stator vanes with intricate shapes, are assembled by brazing. Prospective filler metals should be compatible with cast, hot-pressed, and HIP-treated titanium aluminides and nickel aluminides.

Another potential and highly desirable brazing application of Ti-based filler metals is joining of heat-resistant titanium matrix composites reinforced by ceramic fibers or particles. Such composites, for example, SiC/β21S containing matrix of β-titanium alloy reinforced with SiC fibers, exhibit tensile strength of 2095 MPa at 68°F (20°C) and 1360 MPa at 1290°F (700°C).

Traditional Ti-15Cu-15Ni filler metal and the majority of Ti-Zr-Cu-Ni-based filler metals are suitable for brazing titanium aluminides and Ti-matrix composites with the joint strength about 0.4-0.5 of that of base metals. Both TiAl alloys and Ti-matrix composites have higher strength than traditional alloys and apparently require a higher strength of joints, especially at high service temperatures.

In order to improve high-temperature performance of brazed joints, the industry needs new brazing filler metals without copper. Such brazing alloys should be based on compositions and microstructures similar or almost similar to intermetallic and composite base metals to provide microstructural and mechanical compatibility with base materials. On the other hand, the potentialities of brazing filler metals based on the Ti-Zr-Cu-Ni system are not exhausted. They can provide higher strength of joints after brazing at the temperature above 1000°C (1832°F).

Two methods of increasing hot strength of titanium brazed joints are discussed in this paper: application of a new high-temperature brazing filler metal TiBraze®1200 (Ni-27Ti-10Al) [2] and brazing with TiBraze®375 (Ti-37.5Zr-15Cu-10Ni) at the temperature which is significantly higher than standard brazing temperature of this filler metal.

2. Experimental

The work was aimed to evaluate: (a) formation of brazed joints by the TiBraze®375 (Ti-37.5Zr-15Cu-10Ni) filler metal heated to 300°C above its routine brazing temperature, (b) metallurgical compatibility of new copper-free brazing filler metal TiBraze®1200 (Ni-27Ti-10Al) with titanium and TiAl base metals, and (c) the shear strength of brazed joints at different temperatures.

The base metals utilized were commercial purity (CP) Grade 2 titanium and hot-pressed/annealed γ-TiAl (Ti-48 at.% of Al) alloy. Compositions and melting ranges of brazing filler metals are presented in Table 1. They were used in the form of pre-alloyed powders (available as Braz1954 and Braz1952 products of Arris International Corp., Berkley, MI), having particle size of -150 mesh/+325 mesh (-100 μm/+45 μm) and in the form of Transfer Tape 0.008" (0.2 mm) thick (Fig. 1). Brazing was carried out in a vacuum furnace at 10^{-4} Torr (10^{-2} Pa). The brazing temperature 2156-2190°F (1180-1200°C) was close to the annealing temperature of γ-TiAl alloy.

Microstructures of brazed samples were analyzed utilizing SEM, and subjected to shear tests at room temperature and at 1000, 1200, and 1470°F (540-800°C). The design specification of mechanical test specimens is shown in Fig. 2.

The thickness and overlap of titanium specimens were varied to get failure of the brazed joint instead of base metal at high temperatures. Thus, the effectiveness of the filler metal in terms of microstructure and overall strength for potential brazing applications could be assessed.

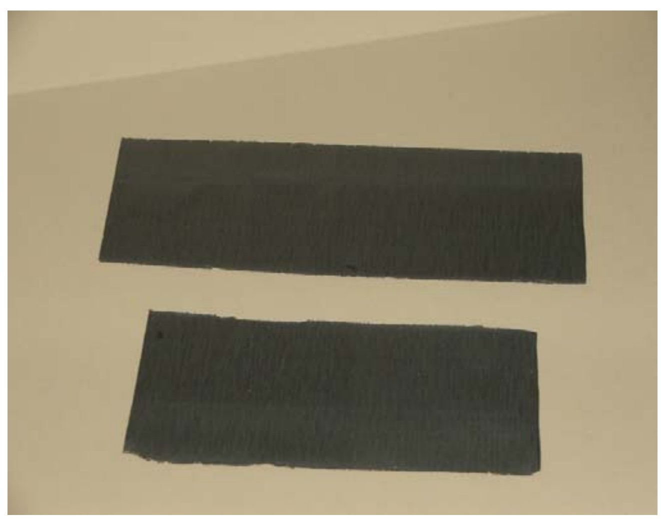

Fig. 1 Transfer tape of TiBraze375 brazing filler metal, thickness 0.008 in. (0.2 mm)

Table 1. Compositions and melting points of brazing filler metals

Composition, wt.%	Solidus, °F (°C)	Liquidus, °F (°C)
Ni-27Ti-10Al	2030 (1110)	2048 (1120)
Ti-37.5Zr-15Cu-10Ni-0.1Cr/Fe	1510 (825)	1535 (835)

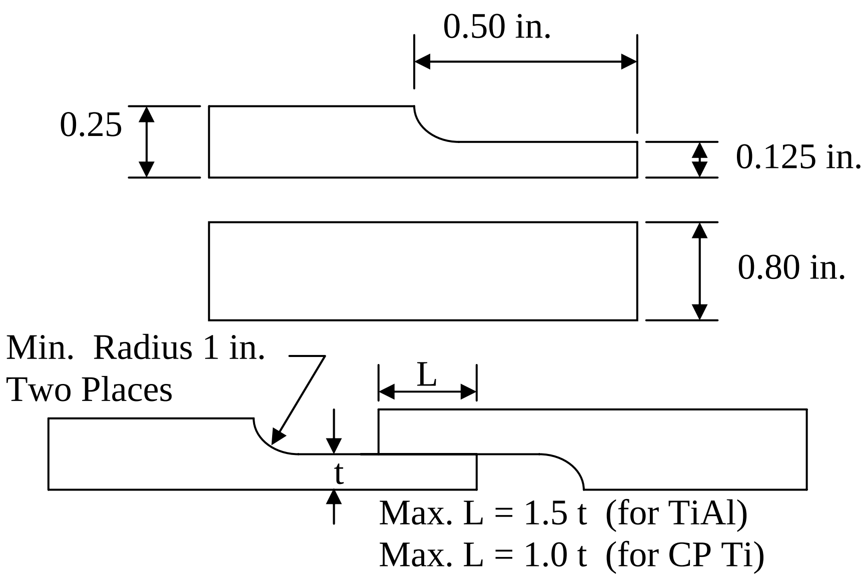

Fig. 2 Design of mechanical test specimen

3. Results and discussion

The Ti-37.5Zr-15Cu-10Ni filler metal exhibited perfect wetting and gap filling of both titanium and titanium aluminide base materials at the temperature of 2156°F (1180°C) which is higher by 570°F (300°C) than usual brazing temperature for this filler metal. The microstructure of TiAl brazed joints (Fig. 2) is characterized by a cast eutectic-based zone in the center and wide diffusion zones on the interfaces with the base metals. The structure of brazed joints is fully dense, without voids. Pores on the interface (Fig. 3) are caused by residual porosity of hot-pressed titanium aluminide base metal. Mechanical testing (discussed below) showed that these pores do not affect shear strength of brazed joints, but theoretically, they may adversely affect creep resistance. Although a fully dense forged or hot-isostatic pressed (HIP) TiAl base metal is preferable for the manufacture of brazed structures dedicated for high-temperature operation, hot-pressed and annealed base metal may be used for brazing experiments.

Brittle intermetallic layers were not observed in the joint microstructure, although intermetallics were always present in titanium joints brazed with the same filler metal but at 1580-1650°F (860-900°C). The absence of intermetallics may result in better plasticity and shear strength of brazed joints than that of titanium joints brazed at lower temperature.

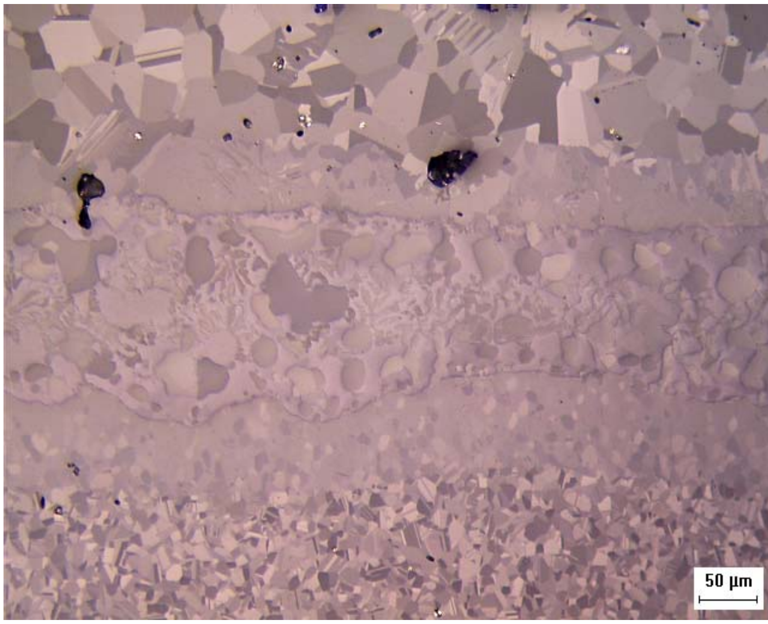

Fig. 3 Microstructure of γ-TiAl (top)-to-titanium (bottom) joint brazed with TiBraze375 (Ti-37.5Zr-15Cu-10Ni-0.1Cr/Fe)

Fig. 4 Microstructure of Ti-to-Ti joint brazed with TiBraze1200 (Ni-27Ti-10Al) filler metal (Joint clearance 0.05 mm (0.002")

New Cu-free brazing filler metal TiBraze1200 (Ni-27Ti-10Al) exhibited perfect wetting and gap filling of titanium-to-titanium joints. The interaction of this filler metal with the base material is characterized by extremely intense diffusion which resulted in total disappearance of the melt and in the formation of a solid uniform joint microstructure (Fig. 4) with the proviso of joint clearances <0.05 mm (0.002").

Joints of clearances 0.05-0.15 mm (0.002-0.006") have dense microstructures characterized by elements normally appearing in all titanium brazed joints: a developed dendritic central area, a thin intermetallic layers at the interface, and a wide "widmanstätten" diffusion zone in the base metal side (Fig. 5). It is interesting to note that this type of lamellar/cellular microstructure was formed in the titanium joint without a presence of copper, and consequently without formation of $(TiZr)_2Cu$ phase as was found by O. Botstein and A. Rabinkin [3]. The martensitic eutectoid structure of α-Ti appears in the zone of nickel diffusion by the same way as it happen due to copper diffusion in the titanium base metal.

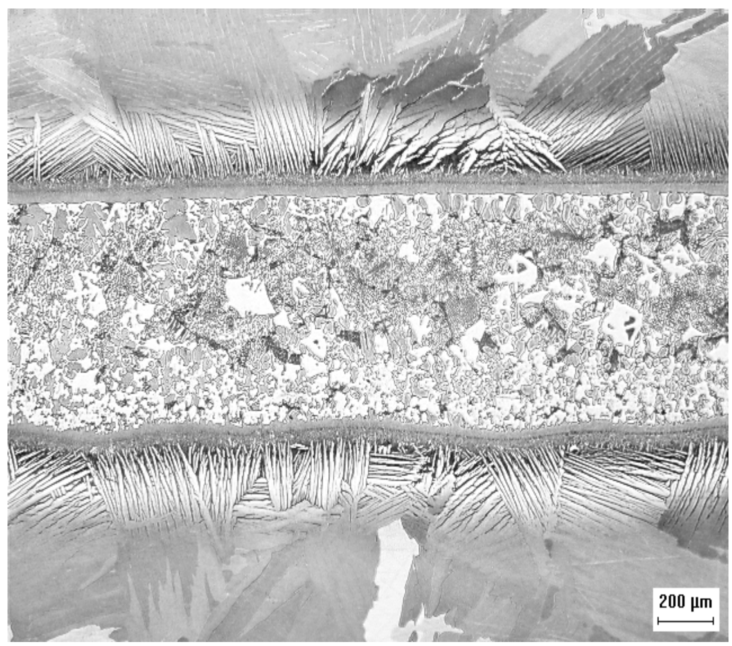

Fig. 5 Microstructure of Ti-to-Ti joint brazed with TiBraze1200 (Ni-27Ti-10Al) filler metal (Joint clearance 0.12 mm (0.005")

However, the TiAl base metal did not react with the Ni-27Ti-10Al filler metal. No wetting occurred neither at 2156°F (1180°C) nor 2190°F (1200°C). This negative effect needs to be investigated, but to a first approximation, it can be explained by very high oxidation ability of hot-pressed titanium aluminide manufactured from the prealloyed powder. We suggest that even vacuum of 10^{-4} torr cannot prevent oxidation of the powder-sintered TiAl base material. The Ni-27Ti-10Al brazing filler metal starts to wet the base metal at the temperature above the braze liquidus of 2050°F (1120°C) and cannot react with the surface containing complex aluminum-titanium oxide.

This point of view is indirectly confirmed by the fact the Ti-37.5Zr-15Cu-10Ni filler metal reacts with titanium aluminide at 2156°F (1180°C), probably because wetting occurs at 1535°F (835°C) which is significantly below of the brazing temperature of the experimental alloy Ni-27Ti-10Al.

In order to improve wetting of hot-pressed titanium aluminide alloys by copper-free brazing filler metals, two methods can be considered for future experiments. Thin layers (2-5 microns) of titanium or nickel deposited on the TiAl surface may prevent early oxidation of the base metal and promote wetting by the Ni-27Ti-10Al. The second approach includes the application of composite brazing filler metals, for example, a powder mixture of said "core" Ni-27Ti-10Al alloy with the Ni-Ti eutectic powder having melting temperature significantly below than that of the "core" powder.

Shear strength of titanium-to-titanium brazed joints made with the Ni-27Ti-10Al brazing filler metal is stable in a wide temperature range. It decreased <10% at 1000°F (540°C) in comparison with the strength at the room temperature. The shear strength of joints brazed with this new filler metal is higher than that of joints brazed with the standard Ti-25Cu-15Ni filler metal [4] (Table 2).

Shear strength of TiAl-to-TiAl joints brazed by the overheated Ti-37.5Zr-15Cu-10Ni filler metal was also higher than that of joints brazed with the standard Ti-15Cu-15Ni filler metal [5] at all testing temperatures, especially in the range of 1200-1470°F (650-800°C). We consider this gain as a result from the intermetallics-free microstructure of brazed joints made with the overheated Ti-37.5Zr-15Cu-10Ni filler metal.

Table 2. Mechanical properties of base metals and brazed joints at different testing temperatures

Base metal	Brazing filler metal	Strength of base metals and brazed joints ksi (MPa) at testing temperatures:			
		RT	1000°F (540°C)	1200°F (650°C)	1470°F (800°C)
CP titanium	-	67 (460)	32 (280)	23 (159)	11 (76)
	Ni-27Ti-10Al	57-62 (393-428)	52-59 (359-407)	Failure of base metal	
	Ti-25Cu-15Ni	41-46 (283-317)	-		
Hot-pressed TiAl	-	90 (620)	92 (635)	98 (680)	81 (560)
	Ti-37.5Zr-15Cu-10Ni	48-55 (331-379)	46-61 (317-421)	63-68 (435-469)	42-47 (287-326)
	Ti-15Cu-15Ni	40 (276)	-	58 (400)	-

4. Conclusions

4.1 The Ti-37.5Zr-15Cu-10Ni brazing filler metal is metallurgically compatible with titanium aluminide alloys and provides a significant gain in hot strength of brazed joints made at the brazing temperature of 2156-2190°F (1180-1200°C).

4.2 New near-eutectic, copper-free brazing filler metal Ni-27Ti-10Al is metallurgically compatible with titanium base metal and can be used for diffusion brazing of titanium and titanium matrix composites. This brazing filler metal provides strength of joints higher than that of traditional Ti-Cu-Ni filler metals both at room temperature and at high temperature.

4.3 In order to use the Ni-27Ti-10Al filler metal for brazing titanium aluminides, brazing temperature should be decreased either by alloying or by using a composite mixture of this alloy with a low-melt alloy, or thin coating film of Ti or Ni should be deposited on the TiAl part to prevent early oxidation of the base metal before melting the filler.

5. References

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