

Microstructural Characterisation of γ -TiAl Joints

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Abstract. The joining of a γ -TiAl alloy using Incusil-ABA as filler metal was investigated. Bonding was performed in a high vacuum furnace at 750 °C for 10 min. The interfacial microstructure was analysed by SEM and its composition was investigated by EDS. An intense diffusion of Ti and Al to the interface and a strong reaction between the braze alloy and the base metal were observed. The interface could be divided into two distinct zones: (1) the reaction layer located near the base metal, essentially composed of Cu-Al-Ti compounds and (2) the central zone of the interface that corresponds to an (Ag) solid solution in which Cu-Al-Ti compounds are dispersed.

Introduction

Owing to their high-temperature strength retention, low density, excellent resistance to ignition and good creep and oxidation resistance, TiAl-based alloys are promising candidates for replacing Ti-based alloys and Ni-based superalloys for structural applications in the temperature range of 400 to 800 °C. Despite the lack of ductility and the low fracture toughness at room temperature of TiAl-based alloys, a special attention has been addressed by the aerospace and automobile industries to implement them in the conception of static and rotary components. Engines valves, turbine blades, airframes, seal supports and cases are some examples. Most of these components have performed well in laboratory tests as well on the “field”; some have already enter into full-scale production, others are expected to enter soon [1-6].

The application of TiAl-based alloys is not limited to high-temperature; there are many components for moderate-temperature applications that are sized to manufacturing tolerances, vibration, aerodynamics, ignition resistance and others. The higher stiffness and lower density of TiAl-based alloys compared to “conventional” metallic materials used by these industries, are major factors when clearances are concerned and weight reduction is imperative [6, 7].

Therefore, the development of adequate techniques to join these alloys to themselves and to other materials is fundamental to integrate them into functional structures and to widen their application field. Diffusion brazing and diffusion bonding are the most reported techniques to produce joints with adequate mechanical properties for high-temperature applications [8-11]. Brazing using Ag-Cu [2] or Ag-Cu-Ti [12, 13] fillers seems to be a more appropriate approach when room or moderate-temperature applications are envisaged: joining is performed at lower temperatures and, contrarily to diffusion bonding, without the need of applying elevated pressures to promote bonding.

This work focuses on the joining of a Ti-47Al-2Cr-2Nb alloy using an Ag-Cu-In-Ti filler (Incusil-ABA) that has a liquidus temperature of 715 °C, which is 100 °C lower than that of the Ag-Cu-Ti filler (Cusil-ABA) generally used for brazing these alloys.

Experimental Procedures

The γ -TiAl alloy (Ti-47Al-2Cr-2Nb, at.%) with a duplex microstructure used in this investigation was produced by Crucible Research. Samples of the γ -TiAl alloy with 10 x 7 x 3 mm were cut with a diamond saw and then polished to a 1 μ m diamond spray finish. An Ag-27.25Cu-12.5In-1.25Ti

(wt.%) alloy foil, Incusil-ABA, with a thickness of 100 μm , was used as brazing filler metal. Prior to joining both materials were degreased in acetone with ultrasonic agitation, dried in air and then assembled into a sandwich type. A small pressure (50 Pa) was applied to the assemblage during the brazing thermal cycle. Brazing was performed at 750 $^{\circ}\text{C}$ for 10 min in a vertical furnace, which was evacuated to a vacuum level better than 10^{-1} Pa. The heating and cooling rates were fixed by a controller at 5 $^{\circ}\text{C}\cdot\text{min}^{-1}$. In order to perform the microstructural and chemical characterisation of the interface, cross-sections of the joints were prepared using standard metallographic techniques. The interfaces were examined by SEM and chemically analysed by EDS at an accelerating voltage of 15 keV.

Results

SEM analysis indicated that the interface could be divided into two distinct zones. For convenience these zones will be designated by letters (*A* and *B*) that are marked in figure 1, in which back-scattered electron images of the interface are presented. The chemical composition throughout the interface is listed in table 1. Unless otherwise stated all compositions are expressed in atomic percentage.

Located near the titanium aluminide, zone *A* is essentially composed of Cu, Al and Ti and has a width of approximately 15-25 μm . This zone presents a chemical composition gradient: Cu, Ag and In contents increase towards the centre of the joint while Al contents decreases. Zone *B* corresponds to the centre of the interface and consists of an Ag rich matrix in which Cu-Al-Ti particles are dispersed. The width of this zone is close to 45 μm and, as it can be observed in figure 1c), most of the Cu-Al-Ti particles are zoned: the centre (*Pc*), is generally surrounded by a darker zone (*Pd*) that has a higher Al contents and a lower Cu contents. EDS analysis performed on the joined titanium aluminide samples detected no trace of the elements of the brazing alloy (Ag, Cu and In).

In order to assess the microstructural and chemical stability of the interface at moderate temperature, a post-joining annealing at 550 $^{\circ}\text{C}$ for 48 hours was performed. In comparison to the as-joined samples neither microstructural or chemical significant changes were observed at the interface of the heat-treated joints.

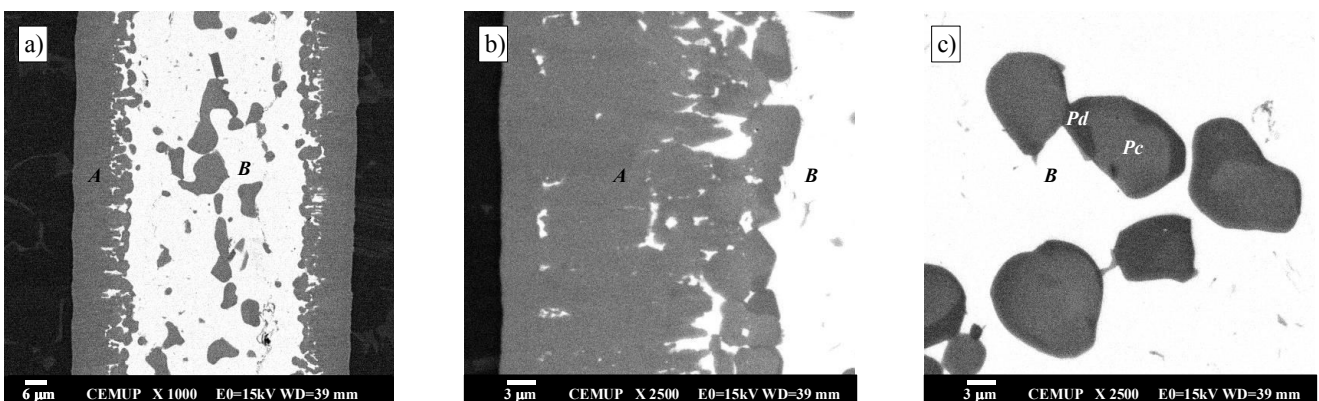


Figure 1 – Microstructure of the interface. a) global; b) magnification of zone *A*; c) Cu-Al-Ti particles in zone *B*.

Table 1 – Chemical composition through the interface.

Zone	Cu	Ti	Al	Ag	In
<i>A</i>	48.7	26.4	22.1	0.7	1.3
<i>A</i> (close to <i>B</i>)	53.6	27.5	14.1	1.2	3.5
<i>B</i>	4.1	0.7	0.7	82.8	11.2
<i>Pd</i>	54.3	27.6	13.2	0.9	3.5
<i>Pc</i>	58.1	27.1	10.9	0.5	3.4

Discussion

Zone *A* is mainly composed of Cu, Al and Ti; therefore the isothermal section of the Cu-Al-Ti system at 500 °C (figure 2) [14], below which there are no invariant reactions, should provide valuable information about the phases that may constitute this zone. The analysis of the isothermal section suggests that zone *A* may essentially consist of AlCu₂Ti. The formation of this compound has been reported in other studies. For instance, Noda et. al. [12] suggested the formation of an AlCu₂Ti intermetallic compound near a TiAl alloy joined by infrared brazing to a structural steel using an Ag-Cu-Ti braze alloy. The formation of this compound is also suggested by Tetsui [2] when a γ -TiAl alloy is joined to a nickel based superalloy with an eutectic Ag-Cu filler. Liu et. al. [13] identified a Ti(Cu,Al)₂ phase located near a Ti-43Al-1Cr-1.7Nb alloy joined to SiC with an Ag-27-Cu-4.5Ti (wt.%) braze alloy.

The matrix of zone *B* is essentially composed of Ag, In and Cu. The isothermal section of the Ag-Cu-In system at 500 °C [15] indicates that it should consist of an (Ag) solid solution. The particles dispersed in the matrix should correspond, as zone *A*, to the AlCu₂Ti compound, once both *Pd* and *Pc* compositions lay on/or very close to the AlCu₂Ti field.

In this investigation no traces of Ag, Cu or In were detected in the titanium aluminide while Al and Ti were detected in high contents throughout the interface. Therefore, the dissolution of the base intermetallic by the braze alloy plays, in this case, a major role than does the diffusion of the braze alloy elements into the base intermetallic. This was an expected result since low solubility of the braze alloy elements in titanium aluminides have been reported, namely of Cu [8] and Ag [16]. No reports have been found about the solubility of In but the results in this investigation indicate that a low solubility limit should also be expected.

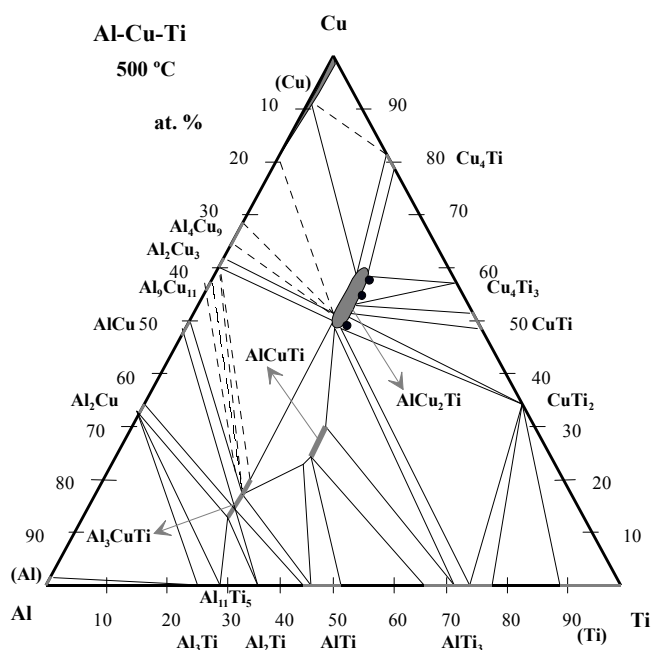


Figure 2 –Isothermal section through the Al-Cu-Ti phase diagram at 500°C [14], where the compositions of zone *A*, *Pc* and *Pd* are marked as black dots.

Based on these considerations we think that the microstructural development at the interface occurs through the following mechanism:

When the braze alloy reaches the liquid state, dissolution of the titanium aluminide and an intense diffusion of Ti and Al into the joint area takes place. Due to the flux of Ti and Al atoms a concentration gradient of Ti and Al will be gradually built up through the interface and eventually the solubility limits of Ti, Al and Cu in the melt will be exceeded. Since these elements have a higher affinity to each other than to Ag or to In, Cu-Al-Ti compounds will begin to form, first

adjacently to the titanium aluminide and then towards the centre of the joint, originating zone *A*. Ag and In will essentially be segregated to the centre of the joint which will be the last to solidify. Diffusion of Ti and Al to the centre of the joint that is still in the liquid state and the high affinity between these elements and Cu, will allow the formation of AlCu₂Ti compounds. When the centre of the joint finally solidifies, these compounds will be entrapped, so that zone *B* will consist of an (Ag) solid solution, with In and Cu being the major solute elements, in which AlCu₂Ti particles are dispersed.

Conclusions

A strong reaction between Incusil-ABA and the Ti-47Al-2Cr-2Nb intermetallic alloy and an intense diffusion of Ti and Al to the interface were observed when bonding was carried out at 750 °C for 10 min. Dissolution of the base intermetallic by the braze alloy seems to play a major role in the establishment of the joining than does diffusion of the braze alloy elements into the base intermetallic.

The bonding interface consists of an AlCu₂Ti phase formed near the base intermetallic alloy and of an (Ag) solid solution located at its centre in which AlCu₂Ti compounds are dispersed.

The joints are able to withstand prolonged periods of time (up to 48 hours, at least) at moderate temperatures (up to 550 °C) without showing at the interface significant chemical or microstructural alterations. Mechanical testing of joints is needed to assess the suitability of INCUSIL-ABA as filler alloy to join γ -TiAl components.

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