Lasers in Manufacturing Conference 2015

Yb:fiber laser joining of Ti-6Al-4V and AA6013 dissimilar metals

A.C. Oliveira[a]*, R. Riva[b], N.M.A. Athanazio[c]

[a]*Universidade Federal de São Paulo, Rua Talim 330, Vila Nair, São José dos Campos – SP, 12231-280, Brazil*
[b]*Instituto de Estudos Avançados, Trevo Cel.Av.José A.A.Amarante 1, Putim, São José dos Campos – SP, 12228-001, Brazil*
[c]*Instituto Tecnológico de Aeronáutica, Praça Mal.Eduardo Gomes 50, Vila das Acácias, São José dos Campos – SP, 12228-900, Brazil*

Abstract

Titanium and aluminum alloys have been considered to applications in structural components of aircrafts. A common phenomenon in Al/Ti joints is the presence of brittle intermetallic compound (IMC) in the junction interface region. Laser beam joining of dissimilar metals can generate acceptable limits of IMC in this region. In the present work, Ti-6Al-4V and AA6013 sheets (1.0 mm and 1.6 mm thick, respectively) were joined by an Yb:fiber laser. Butt joints were conducted by varying the relative positioning of laser beam toward Al alloy, from 0 (interface joint) up to 0.5 mm. The welding speed and the laser average power were fixed , 3.0 m/min and 1000 W, respectively. Metallographic analyses were performed on the joint cross-section by optical microscopy. The positioning of laser beam has a pronounced influence on the quality of the joints. Between 0.2 and 0.4 mm, the Ti alloy was not melted, promoting a joint with no severe defects. On other hand, when the laser beam was positioned near of the interface area, a melted region containing a mixture of titanium and aluminum was formed with the presence of some defects. EDS line scanning in the junction interface showed a decreasing of IMC layer in the joints without melted titanium alloy, i.e., with laser beam positioned toward Al alloy between 0.2 and 0.4 mm. The thickness of interfacial IMC layer was about 15-30 times lower than the interfacial IMC layer for the melted Ti alloy condition, reaching the mean value of 15 µm.

Keywords: joining; dissimilar metals; Yb:fiber laser

1. Introduction

Dissimilar joining betwem titanium and aluminium alloys has potential application in aerospace industry, particularly in structural components of aircrafts [Vaydia et al.,2010]. Several techniques have been used in

* Corresponding author. Tel.: +55-12-3309-9600.
E-mail address: aline.capella@unifesp.br.

the junction de titanium and aluminium alloys: brazing, diffusion bonding, friction stir welding and electron beam welding [Chen et al.,2010]. Laser joining process has been considered as an attractive alternative due to its great flexibility, high energy density, a narrower interaction zone, faster heating and cooling rates and small distortion [Tusek et al.,2001].

Independently of the process, the junction of dissimilar metals can form brittle intermetallic compounds (IMC) in the joint interface, degrading the mechanical properties of the material [Vaydia et al.,2009; Sun and Karppi, 1996]. Some works have been conducted to decrease the thickness of the interfacial IMC. Jiangwei et al.,2002 demonstrated that in the diffusion bonding, the diffusion phenomenon occurs only in the titanium alloy. Explosion welding process was considered effective in the IMC inhibition, although the process is limited by the material thickness [Ege and Inal,2000]. Studies [Ghosh et al.,2010; Aonuma and Nakata,2009] have considered the friction stir welding for joining dissimilar metals, since the process does not involve the fusion of the materials. However, this process is restricted to simpler geometries, as butt or overlap welding. Other works introduced silicon in the junction interface to control of IMC thickness. Chen et al,2010 have indicated that $Ti_7Al_5Si_{12}$ and Ti_5Si_3 phases, formed in the junction interface, inhibit the formation of Al_3Ti and $AlTi_3$ brittle intermetallics. Takemoto and Okamoto, 1988 demonstrated the vacuum brazing using filler wires with different compositions. The results showed that the introduction of silicon filler wire improves the mechanical properties of the Ti/Al junction. However, the use of filler wire can limit the process efficiency since the process parameters are quite complex and defect generation must be strictly controlled.

Although the behavior of the Ti/Al laser junction has been demonstrated, the influence of the laser parameters on the interfacial IMC layer morphology have not been enough investigated. Literature has shown that a precise control of the laser process parameters enable dissimilar metal junctions with acceptable IMC thickness, minimizing the negative effects on the junction mechanical properties [Song et al.,2013; Schubert et al.,2001].

In the present work, Yb:fiber laser joining of Ti-6Al-4V and AA6013 without filler wire was performed. The main goal of this research is to evaluate the relationship between the laser process parameters, the microstructure and the IMC layer, in order to optimize de junction process.

2. Experimental details

Sheets of titanium alloy, Ti-6Al-4V, with 1.0 mm thickness, and aluminium alloy, 6013-T4, with 1.6 mm thickness, were used. The chemical composition of the sheets is presented in Table 1. The 20 mm x 25 mm metal sheets were tightly clamped and fixed on a XYZ CNC moving table. Before processing, all sheets were cleaned with abrasive paper (SiC grit 600) and ethanol to remove the residual grease and any contaminants.

Fig. 1 shows the schematic diagram of the joining experiment. A high-power Yb:fiber laser with a 2 kW maximum power (IPG, YLS 2000) was used in the experiments. Using a lens with focal length of 160 mm, the laser beam was focused on the sample with estimated diameter of 100 µm [Oliveira et al.,2015]. Butt joints were conducted by varying the beam displacement from the interface junction toward Al alloy, between 0 (at the junction interface) up to 0.5 mm, maintaining the welding speed and the laser average power at 3.0 m/min and 1000 W, respectively. Helium with a flow rate of 20 L/min was used as shielding gas.

Table 1. Chemical composition of Ti-6Al-4V and AA6013-T4 (%).

Alloys	Ti	Al	V	Si	Cu	Fe	Mg	Mn	Others, total
Ti-6Al-4V	Balance	6,80 ±0,02	4,36 ±0,04	…	0,05 ±0,04	0,39 ±0,02	…	…	0,08± 0,02
AA6013-T4	…	Balance	…	0,62 ±0,02	0,82 ±0,02	0,20 ±0,02	0,94 ±0,05	0,27 ±0,04	0,06 ±0,01

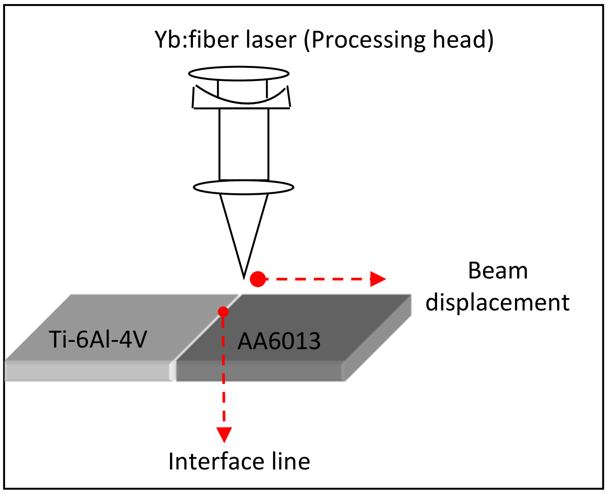

Fig. 1. Schematic diagram of the joining experiment, showing the variation of beam positioning along of interface junction toward Al alloy.

Metallographic analyses were performed on the junction cross-section by optical microscopy (OM). The specimens were grinded with abrasive paper (SiC grits of 240, 400, 600 and 1200, respectively), polished to a mirror finish (Al_2O_3 solution of 1 µm and colloidal SiO_2) and chemically etched using Keller's reagent (2 ml of HF, 1 ml of HNO3 and 88 ml of H2O). The IMC laser was observed by scanning electron microscopy (SEM, JEOL JSM 6701S) equipped with an energy dispersive X-ray spectrometer (EDS). Hardness measurement (Microhardness, Shimadzu HMV-2) was performed on cross-section of the specimens using a Vickers indenter and a load of 490 mN.

3. Results and Discussions

Butt joints were performed by varying the laser beam positioning along of interface junction toward Al alloy. The main aim was to evaluate the influence of this parameter on the formation of joints. The joint cross-sections at different laser beam displacements are shown in Fig.2. When the laser beam was positioned in the interface line (Fig.2-a) displaced 0.1 mm (Fig.2-b) toward Al alloy, both titanium and aluminium alloys are melted at the joint interface (Fig.2-a), generating a mixed compound fusion zone. Studies [Song et al.,2013; Majumdar et al.,1997] have shown that this mixed fusion region is formed by different compounds, specially, $TiAl_3$, $TiAl_2$, TiAl and Ti_3Al, which deteriorates the junction mechanical efficiency. When laser beam was displaced 0.2, 0.3 and 0.4 mm (Figs. 2-c to 2-e, respectively) toward Al alloy, the titanium alloy is not melted, while the melted aluminium alloy wets the junction interface, generating the junction between the dissimilar metals.

The grain size in fusion zone of Al alloy does not varies for the different joint conditions. Similarly to observed in previous work [Oliveira et al, 2015], the fusion zone of Al alloy exhibits a fine cellular dendritic solidification structure with many equiaxed grains in the weld centerline (Fig.3-a). Fig.3-b shows the heat-affected zone (HAZ) adjacent to the interface of Ti alloy side. Although the Ti alloy is not melted when the laser beam was positioned between 0.2 and 0.4 mm toward Al alloy, the thermal cycle of the process modifies the microstructure of this region. Song et al, 2013 have been associated these changes to increasing of volume fraction of α phase and decreasing of β phase when compared with Ti alloy base metal.

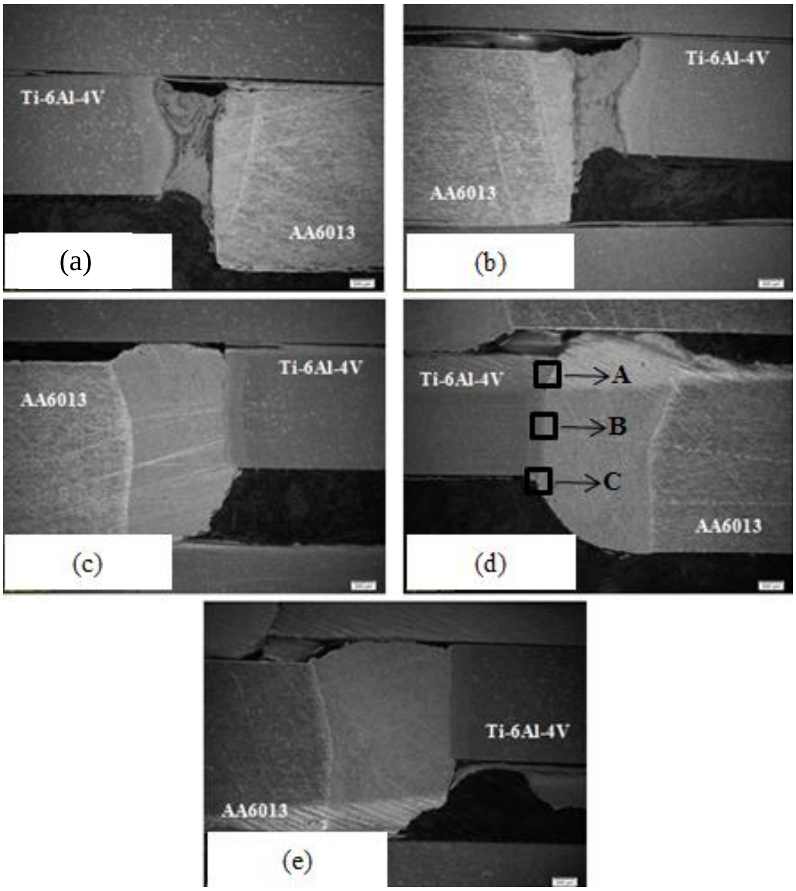

Fig.2 Cross-section of Ti/Al joints with different laser positions: (a) interface line, (b) 0.1 mm, (c) 0.2 mm, (d) 0.3 mm and (e) 0.4 mm.

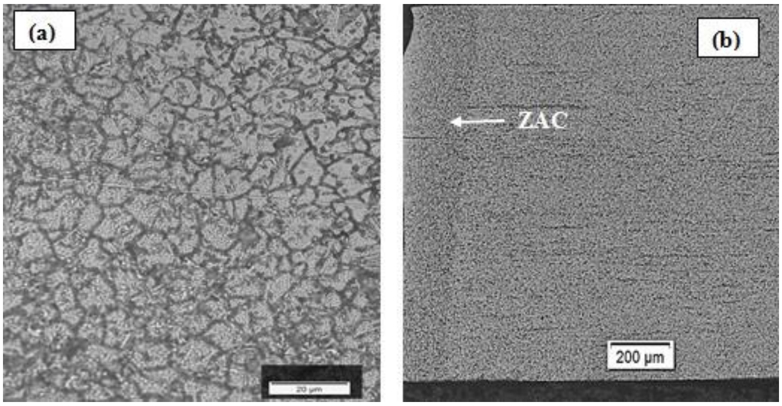

Fig.3 Microstructure of the joint (a) on the side of Al alloy and (b) the heat-affected zone (ZTA) on the side of Ti alloy.

Fig.4 exhibits the interfacial microstructure of three zones of the joint (A, B and C shown in the Fig.2-d), with the laser beam positioned at 0.3 mm toward Al alloy. It can be seen the reaction layer with non-uniform thickness along of interface transverse section. Similary to observed in previous works [Vaydia et al.,2009;Chen et al.,2010]., the reaction layers, at the A, B and C zones, exhibit club-shaped and cellular/serration-shaped morphologies.

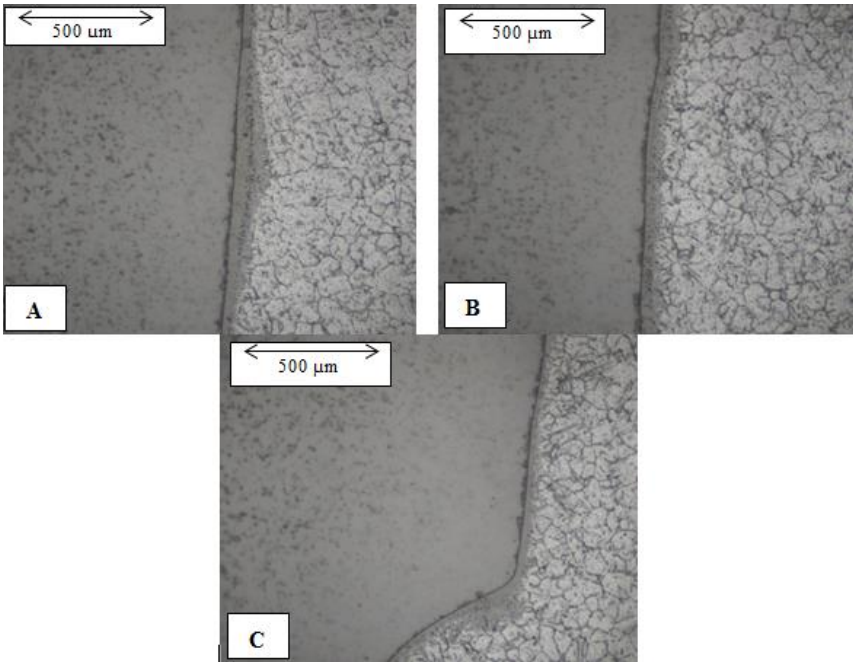

Fig.4 Magnified micrographs of the interfacial microstructures of zones A-C indicated by rectangle in Fig.2-d.

Fig.5 shows the element distribution at junction interface, comparing the results obtained of joints with (Fig.5-a) and without (Fig.5-b) melting of Ti alloy. When the aluminium and titanium alloys are melted, the extensive region of diffusion of aluminium toward titanium alloy of order of 300 µm is observed, (Fig.5-a). On other hand, when the titanium alloy is not melted and aluminium alloy wetted the junction interface only a thin interfacial IMC layer is formed in the junction interface, (Fig.5-b). In these conditions the thickness of interfacial IMC layer is of order of 15 µm.

Table 2 summarizes the phase compositions in different points of the curve (Fig.5-b), denoted by P1-P4. Based on the Al-Si binary phase diagram (Fig.6, [Cao,2013]) the possible phases of each some zones are estimated. It is observed a continuous layer between P2 and P4 zones, near the interface region and toward aluminium alloy, composed mainly of $TiAl_3$ IMC. In addition, it is observed a thin layer in the transition interface between the alloys composed of TiAl phase.

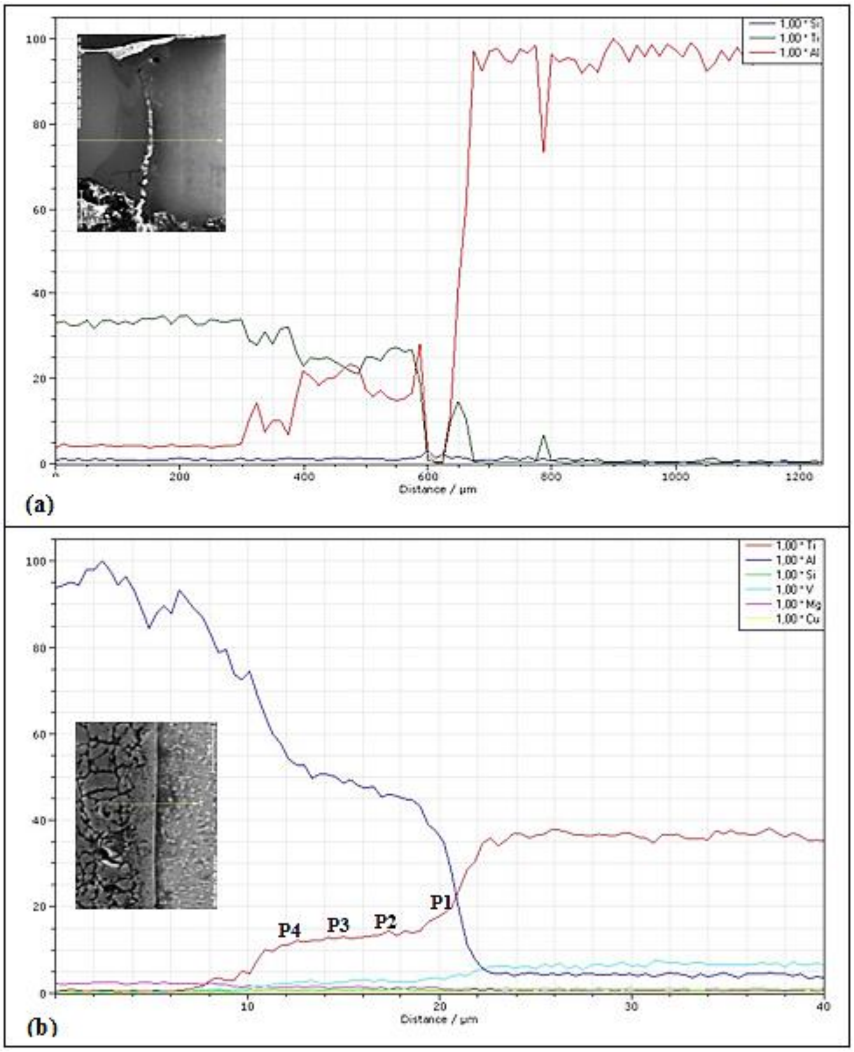

Fig.5 Line scan results showing the diffusion zones of the alloy elements in joint process, considering (a) the melted titanium alloy and (b) the aluminium wetting on the junction interface.

Table 2 Composition and phase of various regions from Fig.5-b.

Point in Fig.5-a	Ti/at.%	Al/at.%	Possible Phase
P1	47.7	52.2	TiAl
P2	27.1	72.9	$TiAl_3$
P3	26.2	73.7	$TiAl_3$
P4	26.7	76.3	$TiAl_3$

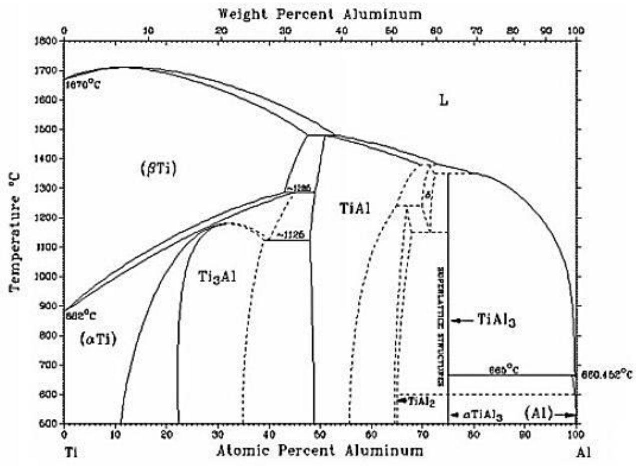

Fig.6 Ti-Al binary phase diagram [Cao,2013].

4. Conclusions

The experimental results reported in this work show the influence of beam positioning on the extension of the IMC layer and the microstructure properties of the fusion zone obtained during the laser joining of Ti and Al alloys. It has been conclude that:

- Between 0.2 and 0.4 mm, the titanium alloy was not melted, promoting a joint with no severe defects. On other hand, when the laser beam was positioned near of the interface area, a melted region of the mixture of titanium and aluminum was formed with the presence of pores and cracks.
- A decreasing of IMC layer was observed in the joints without melted titanium alloy, i.e., with laser offset toward Al alloy between 0.2 and 0.4 mm. The thickness of interfacial IMC layer was about 15-30 times lower than the interfacial IMC layer with the melted Ti alloy condition, reaching the mean value of 15 µm.
- The main phase observed when the aluminium alloys wetted the titanium alloy were TiAl and $TiAl_3$. Further studies will associate the influence of IMC layer, and its composition, on the fracture behavior of the joint.

Acknowledgements

Financial support from FAPESP (process n° 2007-03910-7) is gratefully acknowledged.

References

Vaidya W.V. et al. Journal of Materials Science 45 (2010), 6242-6254.
Chen S. et al. Transactions of Nonferrous Metals Society of China, v.20, p.64-70, 2010.
Tusek J. et al. Journal of Materials Processing Technology, v.119, p.180-184, 2001.
Vaidya W.V. et al. Mat.-wiss.u.Werkstofftech, v.40, p.623-633, 2009.
Sun Z., Karppi R. Journal of Materials Processing Technology, v.59, p.257-267, 1996.
Jiangwei R. et al. Materials Letters, v.56, p.647, 2002.
Ege E.S., Inal O.T. Materials Science Letters, v.19, p.1533, 2000.
Ghosh M. et al. Materials and Design, v.31, p.3033-3037, 2010.

Aonuma M., Nakata K. Materials Science and Engineering B, v.161, p.46-49, 2009.
Takemoto T., Okamoto I. Journal of Materials Science, v.23, p.1301-1308, 1988.
Song Z. et al. Materials Science Engineering A, v.560, p.111-120, 2013.
Schubert E. et al. Journal of Materials Processing Technology, v.115, p.2-8, 2001.
Oliveira A.C. et al. Materials and Design, v.65, p.726–736, 2015.
Majumdar B. et. Journal of Materials Science, v.32, p.6191-6200, 1997.
Chen Y. et al. Materials and Design, v.31, p.227–233, 2010.
Cao R. Science and Technology of Welding and Joining, v.18 (5), p.425-433, 2013.