Optics and Laser Technology 100 (2018) 109–118

Contents lists available at ScienceDirect

Optics and Laser Technology

journal homepage: www.elsevier.com/locate/optlastec

Full length article

Low temperature heat treatments of AA5754-Ti6Al4V dissimilar laser welds: Microstructure evolution and mechanical properties

P. Leo [a,*], S. D'Ostuni [a], G. Casalino [b]

[a] Innovation Eng. Dept., University of Salento, Via per Arnesano s.n., 73100 Lecce, Italy
[b] DMMM, Politecnico di Bari, Viale Japigia, 182, Bari, Italy

ARTICLE INFO

Article history:
Received 26 April 2017
Received in revised form 31 July 2017
Accepted 26 September 2017

Keywords:
Ti-6Al-4V
AA5754
Laser welds
Heat treatments
Microstructure
Mechanical properties

ABSTRACT

This paper presents the effects of the post welding heat treatments (PWHT) performed at 350 °C and 450 °C on the microstructure evolution and mechanical properties of AA5754 and Ti6Al4V dissimilar laser welds. The microstructure and tensile properties of the welds before and after low temperature treatment were analyzed.

The off-set welding technique was applied to limit the formation of brittle intermetallic compounds during the welding process. The laser beam was directed onto the titanium side at a small distance from the aluminum edge. The keyhole formed and the full penetration was reached in the titanium side of the weld. Thereafter, the aluminum side melted as the heat that formed the keyhole transferred from the titanium fused zone. Two different energy lines (32 J/mm and 76 J/mm) were used. In this manner, a fused and a heat affected zones was revealed on both sides of the weld. Several intermetallic compounds formed in the intermetallic layer between the two metals. The thickness and the composition of the intermetallic layer depended on the welding parameters and the post welding heat treatment.

The hardness and tensile properties of the welds before and after the post welding heat treatment were measured and analyzed.

1. Introduction

Dissimilar Aluminium-Titanium joints have aeronautical and automotive several applications. In those industries, the combination of both low weight and high mechanical performances is a key factor in materials selection. Ti-6Al-4V alloy shows an excellent combination of properties, such as low density, very high specific resistance and high corrosion resistance. During laser welding, the fusion zone (FZ) and the heat affected zone (HAZ) of Ti-6Al-4V alloy generally have a hard martensitic structure [1] induced by the high cooling rate. AA5754 Aluminum alloy is widely used thank to its low weight and good weldability. Based on the Al-Mg system, the AA5754 alloy hardens primarily by solid solution and grain refinement [2]. It is also possible to improve the mechanical properties of the AA5754 fiber laser weld with post welding heat treatments [3]. Moreover, when the alloy is welded in the annealed state, the hardness of the HAZ is usually not deteriorated.

Unfortunately, when Al and Ti are joined together, the mechanical properties of dissimilar Al-Ti joints are deteriorated by a hard and brittle layer of intermetallic compounds (or interlayer) that forms in the fusion zone due to the chemical, physical and thermal differences of the alloys. Explosive welding [4], diffusion-bonding [5], brazing [6] and friction stir welding [7] have been widely used to joint aluminum to titanium, since the reduction in convective mixing and diffusion phenomena greatly restrict the formation of intermetallic compounds.

Laser welding is an attractive technique for joining dissimilar materials, particularly if special combination of metals is required [8]. Focusing the beam on the Al side [9,10], the bond with the solid surface of Titanium (fusion-brazing) is promoted and therefore the formation of the interlayer is reduced. In that case, the weld can be strongly affected by porosity [10]. Therefore, in some other studies, the laser beam was focused on the Ti side. The distance from the interface varied to limit the Ti and Al mix and related intermetallic formation [11].

The morphology and composition of the intermetallic layer play a fundamental role on the tensile properties of Al-Ti dissimilar weld [12].

Many works in literature show the presence of distinct types of intermetallic compound between aluminum and titanium, such as Ti_3Al and $TiAl_3$, with different thicknesses depending on the process parameters [11–13].

* Corresponding author.
E-mail address: paola.leo@unisalento.it (P. Leo).

https://doi.org/10.1016/j.optlastec.2017.09.039
0030-3992/

Table 1
Chemical composition of AA5754 aluminum alloy (weight %).

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.40	0.40	0.10	0.50	2.6–3.6	0.30	0.20	<0.15	Bal.

Table 2
Chemical composition of Ti-6Al-4V alloy (weight %).

C	Fe	N_2	O_2	Al	V	H_2	Ti
<0.08	<0.25	<0.05	<0.2	5.5	3.5	<0.0375	Bal.

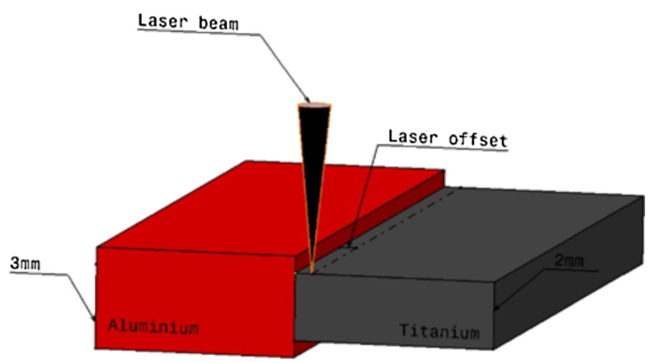

Fig. 1. Scheme of laser welding on AA5754/Ti6Al4V.

Table 3
Welding process parameters.

Sample	Power [W]	Welding speed [mm/min]	Linear energy [J/mm]	Laser offset [mm]
A	1200	1000	72	1
B	1200	2000	36	1

Table 4
PWHT temperatures and times.

PWHT	Temperature [°C]	Time [h]
HT_350	350	336
HT_450	450	168

Some studies have investigated the effect of post welding heat treatments on the microstructure of the intermetallic layers and on the mechanical properties of Al-Ti welds produced by not fusion welding processes, such as friction stir welding and explosive bonding. Li et al. [14] reported the effects of heat treatment on Al/Ti-6Al-4V interface microstructure of bimetal clad-plate fabricated via friction stir lap welding. They found that a well homogenized interlayer improves the clad-plate bonding strength. In Ti/Al clads manufactured by explosive welding the initial stages of the $TiAl_3$ growth have been observed at temperature of 552 °C [15].

At the date, no study is available on the evolution of the microstructure and mechanical properties of Al-Ti fiber laser-welded intermetallic compounds induced by the post welding heat treatment (PWHT). Particularly, the role of low temperature heat treatments (lower than 500 °C) on the metallurgy of Al-Ti interlayer and weld's mechanical properties has not been explored, yet.

In this study, the microstructural evolution of the intermetallic layer in AA5754/Ti-6Al-4V laser joints due to PWHT has been analyzed respect to welds which were processed with different line energies. After the heat treatments, the hardness and tensile properties of the welds were measured and analyzed.

2. Experimental setup

The chemical compositions of as—received Al and Ti alloys are shown in Tables 1 and 2.

Butt joints AA5754/Ti-6Al-4V have been processed on plates 3mm/2mm thick as it is shown in the sketch in Fig. 1.

The laser beam has been focused on the Titanium side (Fig. 1), 1 mm away from the aluminum edge, which is called laser offset. An Ytterbium Fiber Laser System (IPG YLS-4000), whit a maximum output power equal to 4 kW was used for the welding. The laser beam was delivered with a diameter equal 200 μm, and has a Beam Parameter Product (BPP) equal to 6.3 mm/rad. The laser beam having a wavelength of 1070.6 nm has been focused in continuous through a lens with focal distance of 250 mm producing a spot diameter of 0.4 mm on the workpiece surface. Argon and helium were employed as shielding gas with volumetric flow rate equal to 10 l/min. Particularly, since helium has a specific weight less than atmospheric air, it has been employed for the bottom surface, while the heavier Argon was used on top surface.

Two welds (named A and B in Table 3) were fabricated using the same laser beam power but different welding speed. The line energy, which is defined as the ratio between the power and the welding speed, was used to distinguish the two welds, hereafter.

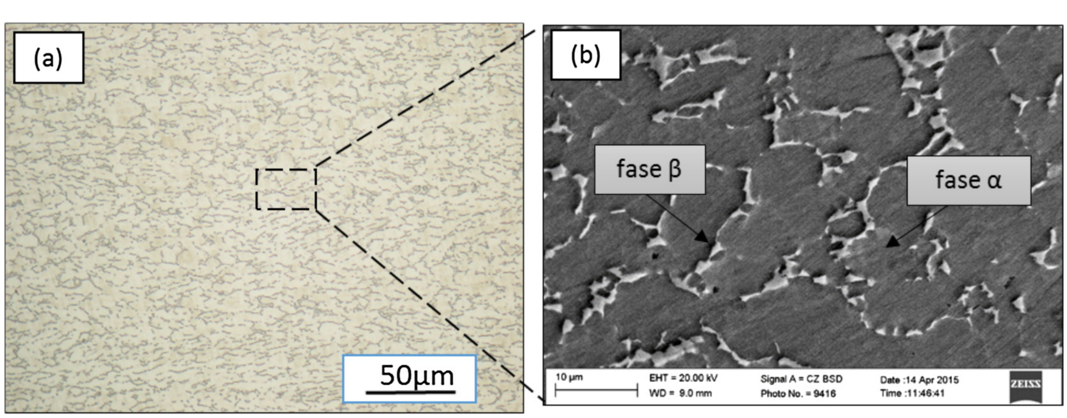

Fig. 2. (a) Optical and (b) SEM micrographs of Ti-6Al-4V as received.