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ScienceDirect
Trans. Nonferrous Met. Soc. China 26(2016) 3135−3146
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Microstructure and mechanical properties of laser beam welded TC4/TA15 dissimilar joints

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Received 25 December 2015; accepted 5 July 2016

Abstract: The microstructure and mechanical properties of laser beam welded dissimilar joints in TC4 and TA15 titanium alloys were investigated. The results showed that the coarse columnar grains containing a large amount of acicular α and martensite α' were present in the fusion zone (FZ), some residual α phases and martensite structure were formed in the heat-affected zone (HAZ) on TC4 side, and bulk equiaxed α phase of the HAZ was on TA15 side. An asymmetrical microhardness profile across the dissimilar joint was observed with the highest microhardness in the FZ and the lowest microhardness in TA15 BM. The orders of yield strength and ultimate tensile strength were as follows: TC4 BM > TC4/TC4 similar joint > TA15 BM > TA15/TA15 similar joint > TC4/TA15 dissimilar joint, and increased while hardening capacity and strain hardening exponent decreased with increasing strain rate from 1×10^{-4} s^{-1} to 1×10^{-2} s^{-1}. The TC4/TA15 dissimilar joints failed in the TA15 BM, and had characteristics of ductile fracture at different strain rates.

Key words: laser beam welding; titanium alloy; dissimilar joint; strain rate; microstructure; mechanical properties

1 Introduction

Titanium alloys have been widely used as structural materials, especially in the fields of aeronautics and astronautics, due to their low specific gravity, high specific strength, excellent fatigue and corrosion resistance and superior mechanical properties at high temperatures [1−4]. TA15 alloy, namely Ti−6Al−2Zr−1Mo−1V, which is a kind of near alpha titanium alloys, has been widely used as structural components of aircraft [5]. TC4 alloy (Ti−6Al−4V), as one of typical alpha-beta titanium alloys, is regarded as a structure titanium alloy with best application prospects, and more than 50% titanium alloy is TC4 alloy. To maximize its light-weighting role, the manufacturing of "hybrid" components from a variety of titanium alloys via proper welding is necessary [6].

There are several welding technologies which can be used to join titanium alloys such as tungsten inert-gas welding, metal inert-gas welding, electron beam welding and laser beam welding (LBW). LBW has drawn particular attention on titanium welding because of its high energy density, low residual stress and high productivity. Compared with electron beam welding, LBW does not need a vacuum environment, and it is more convenient, facile and saving. Besides, it is easy for titanium to get larger depth-to-width ratio of LBWed joint due to some special physical characteristics like lower thermal conductivity and higher infrared light absorptivity [7].

The microstructure, microhardness distribution and mechanical properties of the LBWed joints of dissimilar titanium have been investigated [8−10]. For example, LEI et al [8] found that HAZ of TC4 side of LBWed Ti−22Al−27Nb/TC4 joint mainly consists of a mixture of martensite α', acicular α, and primary α phase, and the ultimate tensile strength of the joints can reach about 92% that of TC4 BM, while the elongation is less than 40% that of TC4 BM. QIAN et al [9] studied the microstructure of TA2/TA15 graded structural material and reported that microhardness distribution of the joint

Foundation item: Project (51405392) supported by the National Natural Science Foundation of China; Project (20136102120022) supported by the Research Fund for the Doctoral Program of Higher Education of China; Project (3102015ZY023) supported by the Fundamental Research Funds for the Central Universities, China
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DOI: 10.1016/S1003-6326(16)64445-X

was asymmetric, which was the result of the solid solution strengthening and the grain boundary strengthening. Besides, the mechanical properties of LBWed BTi−643S/TA15 dissimilar joint were also tested at 550 °C and found that the tensile strength drastically declined, but the tensile ductility was greater than that obtained at room temperature [10]. And some other scholars explored the possibility of laser beam welding of other different materials like titanium and aluminum [11,12], titanium and stainless steel [13]. However, there are almost no related reports about the effect of strain rate on dissimilar titanium joint and it is unclear what microstructure characteristics would be present and how mechanical properties at different strain rates would change in LBWed dissimilar TC4 and TA15 titanium alloys. The objective of this study is, therefore, to examine the microstructure evolution and explore effects of strain rates on tensile properties of LBWed TC4/TA15 joints at different welding speeds and laser powers.

2 Experimental

Two kinds of annealing rolled plates of titanium alloys were utilized for laser beam welding with dimensions of 200 mm × 80 mm × 2.5 mm. The microstructure of TC4 titanium alloy is composed of α phase and fine β phase which is distributed at the elongated α grain boundaries, as shown in Fig. 1(a). The microstructure of TA15 titanium alloy consists of primary α phase and a small amount of β phase, as shown in Fig. 1(b). And the chemical composition of titanium alloys is listed in Table 1. LBW was performed using YLS−4000 fiber laser which has a focal length of 250 mm and a diameter of focused light spot of 0.33 mm. Based on prior researches, these experiments which adopted different welding speeds and laser powers were used to explore the effect of welding parameters on welded joints. In order to protect the welded joint from oxidation, high purity argon was employed as a front shielding gas, a positive shielding gas and a back shielding gas with flow rates of 15, 25 and 10 L/min, respectively (Fig. 2). Table 2 shows the welding parameters (welding speeds and laser powers) of LBWed TC4 and TA15 titanium alloy joints.

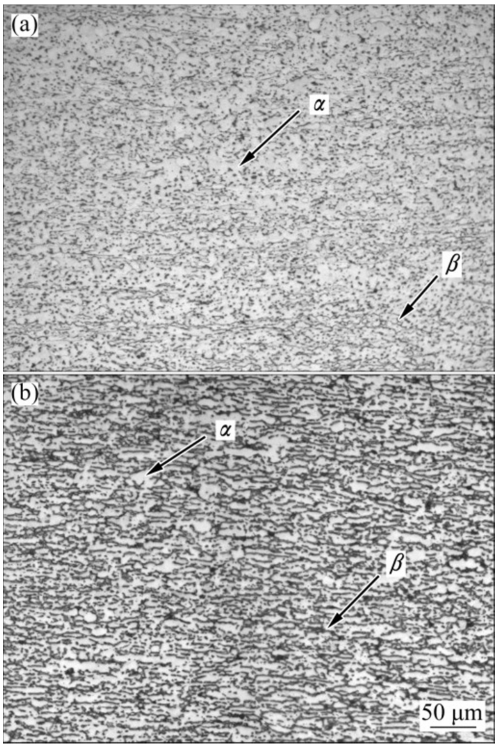

Fig. 1 Microstructures of base materials: (a) TC4 titanium alloy; (b) TA15 titanium alloy

Table 1 Chemical composition of titanium alloys

Material	Mass fraction/%				
	Al	V	Fe	C	Mo
TC4	6.06	3.92	0.30	0.013	−
TA15	6.72	2.32	0.08	0.0053	1.77

Material	Zr	Si	N	H	O	Ti
TC4	−	−	0.014	0.0014	0.15	Bal.
TA15	2.19	0.14	−	−	−	Bal.

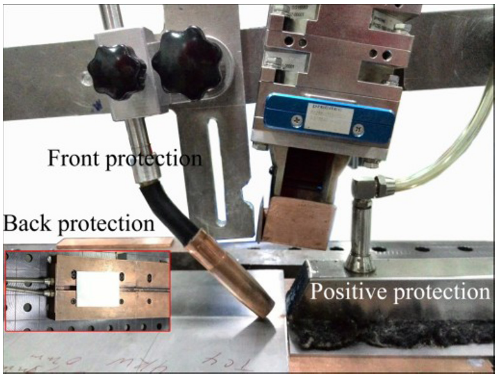

Fig. 2 Gas protective device of laser welding

Table 2 Welding parameters of titanium alloys

Test No.	Laser power/kW	Welding speed/ (m·min^{-1})	Type of joint
1	4.1	5	Dissimilar joints
2	4.1	4	Dissimilar joints
3	4.1	3	Dissimilar joints
4	4.1	2	Dissimilar joints
5	3.3	2	Dissimilar joints
6	2.5	2	Dissimilar joints
7	4.1	4	Similar joints of TC4
8	4.1	4	Similar joints of TA15

Metallographic samples were cut from LBWed joints perpendicular to the welding direction, then

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