Optics and Lasers in Engineering 47 (2009) 1231–1241

Contents lists available at ScienceDirect

Optics and Lasers in Engineering

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

Effect of welding speed on butt joint quality of Ti–6Al–4V alloy welded using a high-power Nd:YAG laser

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ARTICLE INFO

Article history:
Received 3 July 2008
Received in revised form
5 May 2009
Accepted 19 May 2009
Available online 13 June 2009

Keywords:
Laser welding
Nd:YAG laser
Ti–6Al–4V
Butt joint
Welding speed

ABSTRACT

Annealed Ti–6Al–4V alloy sheets with 1 and 2 mm thickness are welded using a 4 kW Nd:YAG laser system. The effects of welding speed on surface morphology and shape, welding defects, microstructure, hardness and tensile properties are investigated. Weld joints without or with minor cracks, porosity and shape defects were obtained indicating that high-power Nd:YAG laser welding is a suitable method for Ti–6Al–4V alloy. The fusion zone consists mainly of acicular α' martensite leading to an increase of approximately 20% in hardness compared with that in the base metal. The heat-affected zone consists of a mixture of α' martensite and primary α phases. Significant gradients of microstructures and hardness are obtained over the narrow heat-affected zone. The laser welded joints have similar or slightly higher joint strength but there is a significant decrease in ductility. The loss of ductility is related to the presence of micropores and aluminum oxide inclusions.

1. Introduction

Presently, Ti–6Al–4V is one of the most widely used titanium alloys, accounting for more than half of all titanium tonnage in the world, and no other titanium alloys threaten its dominant position [1,2]. It is a two phase $\alpha+\beta$ alloy, with aluminum as the alpha stabilizer and vanadium as the beta stabilizer. Due to its high strength and low density, along with good tensile and creep properties up to about 300 °C, Ti–6Al–4V alloy is widely used for turbine disks, compressor blades, airframe and space capsule structural components, rings for jet engines, pressure vessels, rocket engine cases, helicopter rotor hubs, fasteners, critical forgings requiring high strength-to-weight ratios, medical and surgical devices [3]. This alloy can be strengthened by heat treatment or by thermomechanical processing. However, the best combination of properties can be obtained by solution heat treatment just under the β-transus temperature (about 985 °C), followed by rapid quenching and ageing.

Conventionally, TIG, plasma arc [4], and electron beam welding [5] have been used to weld titanium alloys. Limited literature on laser welding of Ti–6Al–4V alloy is available and most of the reports have concentrated on CO_2 laser [1,2,6,7]. Sun et al. [4] compared the parameters and microstructures for TIG, plasma, and CO_2 laser welding of 5-mm-thick sheets of Ti–6Al–4V alloy. It was found that for all the welding processes, sufficient shielding protection of the heated weld area (above 400 °C) was crucial for producing successful joints. The depth and width of the welds produced by laser welding were found to decrease with increasing welding speed. In terms of microstructure, higher current levels for TIG and plasma, as well as lower speeds for laser welding produced larger grain sizes due to the increase in heat input [4]. Laser welds produced much smaller grains than either TIG or plasma. The hardness of the fusion zone increased with increasing welding current for both plasma and TIG welds, and with increasing welding speed for laser [4]. Laser welding produced much harder welds than either plasma or TIG welding due to the high cooling rates. As is well known, high power continuous wave solid-state Nd:YAG lasers were introduced into the aerospace industry only recently. To date, little has been reported on the weldability of Ti–6Al–4V alloy using high power continuous wave solid-state Nd:YAG lasers. In this study, the effect of welding

Table 1
Processing parameter for Ti–6Al–4V alloy used in this study.

Sample no.	Thickness (mm)	Speed (m/min)	Notes
T4	1	4.5	X-ray examined
T3	1	6.0	X-ray examined
T9	1	7.5	
T11	1	9.0	Critical penetration
T13	1	9.0	Second-sided welding for T11
T10	1	10.5	Lack of penetration
T12	1	10.5	Second-sided welding for T10
T15	2	3.0	Wide top bead
T8	2	4.5	X-ray examined
T6	2	6.0	X-ray examined
T14	2	7.5	Lack of penetration
T16	2	7.5	Second-sided welding for T14

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doi:10.1016/j.optlaseng.2009.05.010

speed on joint quality of Ti–6Al–4V alloy is investigated using a 4 kW Nd:YAG laser welding system.

2. Experimental procedures

The material used was mill-annealed Grade 5 Ti–6Al–4V titanium alloy sheets, with two thicknesses of nominally 0.04″ and 0.08″ (referred to as 1 and 2 mm, respectively). The corresponding actual thicknesses are approximately 1.07 and 2.15 mm, respectively. Each specimen had approximate size of $155 \times 100\,\text{mm}^2$, with the longitudinal direction in the welding direction. The faying surfaces of all titanium alloy sheets were brushed and cleaned by methanol to remove any contaminants prior to the clamping. The welding equipment used is a 4 kW continuous wave (CW) solid-state Nd:YAG laser system equipped

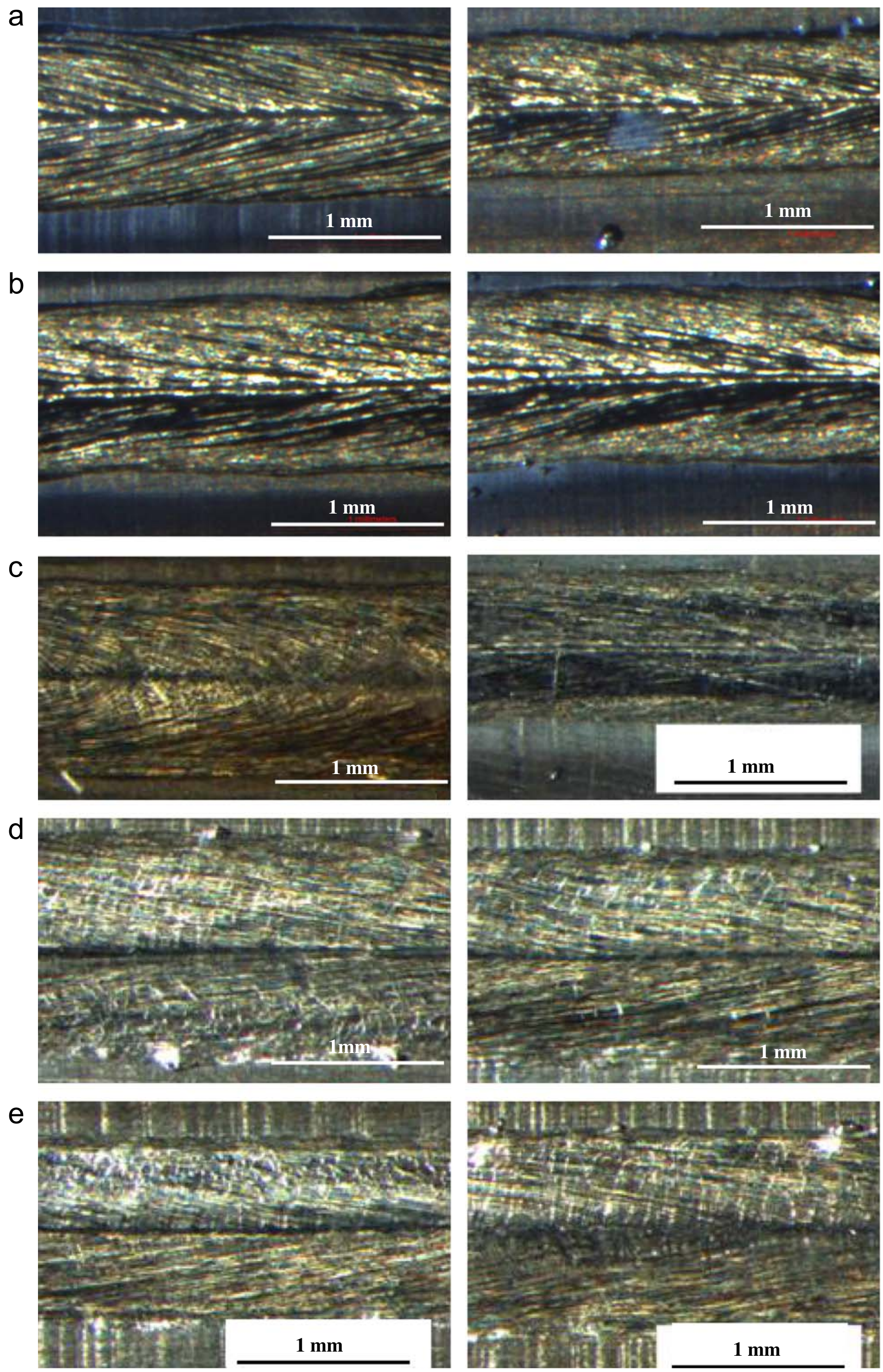

Fig. 1. Stereoscopic micrographs indicating typical surface morphologies of 1 mm sheets at welding speeds (a) 4.5, (b) 6.0, (c) 7.5, (d) 9.0 and (e) 10.5 m/min, respectively. The left column is the top surface. The right column is the root surface for (a–c) but the second-sided welding surface for (d–e) (the welding direction is from the right to the left).