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ScienceDirect
Trans. Nonferrous Met. Soc. China 26(2016) 93−99
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Effect of grain size of primary α phase on bonding interface characteristic and mechanical property of press bonded Ti−6Al−4V alloy

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Received 16 March 2015; accepted 26 August 2015

Abstract: The effect of grain size of primary α phase on the bonding interface characteristic and shear strength of bond was investigated in the press bonding of Ti−6Al−4V alloy. The quantitative results show that the average size of voids increases from 0.8 to 2.6 μm and the bonding ratio decreases from 90.9% to 77.8% with an increase in grain size of primary α phase from 8.2 to 16.4 μm. The shape of voids changes from the tiny round to the irregular strip. The highest shear strength of bond can be obtained in the Ti−6Al−4V alloy with a grain size of 8.2 μm. This is contributed to the higher ability of plastic flow and more short-paths for diffusion in the alloy with smaller grain size of primary α phase, which promote the void closure process and the formation of α/β grains across bonding interface.

Key words: grain size; bonding interface; void closure; shear strength; press bonding; Ti−6Al−4V alloy

1 Introduction

Titanium alloy has a variety of excellent physical and mechanical properties, which include high specific strength, good corrosion resistance and superior heat resistance [1,2]. It has been used to manufacture the lightweight components for aircraft. Press bonding is an effective and precise bonding method for titanium alloy, by which a bond with aspired microstructure and mechanical properties comparable to that of base alloy can be obtained in a short time [3]. As one of the solid state bonding method, it is suitable to bonding the components with complex inner structure.

The performance of press bonded components is mainly dependent on the microstructure and mechanical property of bond, which is controlled by two processes including the void closure and metallurgical bonding. In these two processes, the mass transfer is driven by the plastic flow and atom diffusion, which is significantly influenced by the grain size of materials and bonding parameters. The metals and alloys with fine grain can be bonded at a lower temperature in the diffusion bonding owing to the better superplasticity [4,5]. This advantage has been adopted to manufacture the aircraft components with lightweight structures by coupling diffusion bonding and superplastic forming technology [6]. At present, many investigations focus on the influence of bonding parameters on the microstructure and mechanical properties of bond [7−10]. However, the influence of grain size on the void evolution and metallurgical bonding is not deeply discussed, especially on the mechanisms of void evolution and metallurgical bonding.

In this work, the press bonding of Ti−6Al−4V alloy with different grain sizes of primary α phase was performed. The void evolution and distribution at the bonding interface with different grain sizes were analyzed qualitatively and quantitatively. The variation of the shear strength of bond with grain size of primary α phase was investigated. The effect of grain size of primary α phase on the bonding mechanisms was discussed.

2 Experimental

The material used in this study is Ti−6Al−4V alloy, of which the chemical composition and the original

Foundation item: Project (2014M562447) supported by the China Postdoctoral Science Foundation; Project (51275416) supported by the National Natural Science Foundation of China; Project (BP201503) supported by the Research Fund of the State Key Laboratory of Solidification Processing (NWPU), China
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DOI: 10.1016/S1003-6326(16)64093-1

microstructure are shown in Table 1 and Fig. 1, respectively. From Fig. 1, it can be seen that the microstructure at room temperature is composed of equiaxed primary α phase with a grain size of about 8.2 μm, few secondary (platelet) α phase and a small amount of intergranular β phase. In order to obtain different grain sizes of primary α phase, the as-received Ti−6Al−4V alloy was heat-treated according to the process shown in Table 2. The measured grain sizes of primary α phase of heat-treated Ti−6Al−4V alloy are listed in Table 2.

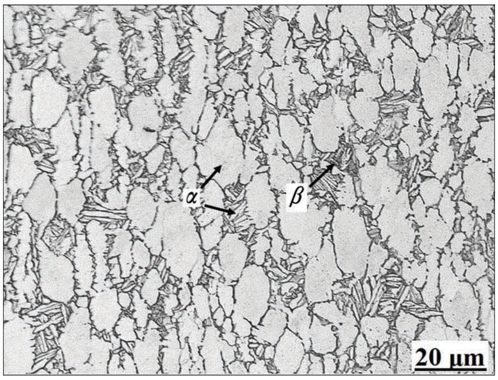

Fig. 1 Optical micrograph of original microstructure of as-received Ti−6Al−4V alloy

Table 1 Chemical composition of as-received Ti−6Al−4V alloy (mass fraction, %)

Al	V	Fe	Si	C	N	O	H	Ti
6.05	4.32	0.22	<0.04	0.024	0.006	0.16	0.003	Bal.

Table 2 Grain sizes of primary α phase of heat-treated Ti−6Al−4V alloy

No.	Heat treatment process	Grain size of primary α phase/μm
1	(930 °C, 2 h) furnace cooling (FC); (650 °C, 2 h), air cooling (AC)	9.8
2	(930 °C, 12 h), FC; (650 °C, 2 h), AC	12.5
3	(930 °C, 48 h), FC; (650 °C, 2 h), AC	16.4

The specimens for press bonding were in the form of cylindrical blocks of 30.0 mm in diameter and 20.0 mm in height. Before press bonding, the surfaces of specimens to bond were ground by using 1000 grit SiC paper to remove the machining marks and oxidation film. The ground specimens were cleaned ultrasonically in ethanol for 10 min and then dried.

Two ground specimens with the same grain size of primary α phase were assembled together and then put into a vacuum hot press. They were heated to a temperature of 850 °C at a heating rate of 15 °C/min as the vacuum degree was up to 5×10^{-3} Pa. After the temperature of the specimens was homogenous, a pressure of 30 MPa was applied to the specimens and kept for 10 min. As the press bonding was completed, the pressure was released and the bonded specimens were cooled in furnace to room temperature.

The height h_0 (mm) of assembled specimens before press bonding and the height h (mm) of bonded specimens after press bonding were measured by vernier calipers. The deformation ratio (e) was proposed to denote the macroscopic plastic deformation of Ti−6Al−4V alloy in the press bonding, which can be calculated as follows:

$$e=(h_0-h)/h_0\times100\% \tag{1}$$

The cross sections of bonded specimens were prepared by standard metallographic method. The bonding interface characteristic was investigated on a TESCAN MIRA3 XMU scanning electron microscope (SEM). The void size was measured by Image-Pro Plus software, which was denoted by the maximum linear length of void along the direction of bonding interface [11]. The bonding ratio was considered as a ratio of the length of bonding interface free of void to the length of the whole bonding interface.

The shear tests of bond and base alloy were conducted on an INSTRON 3382 universal test machine with a crosshead speed of 1.0 mm/min. The geometry of shear test samples is illustrated in Fig. 2. The arrows and dash-dot-line present the direction of shearing force and shear plane, respectively. The shear plane located at the bonding interface. The morphologies of shear fracture surfaces were observed on TESCAN MIRA3 XMU SEM.

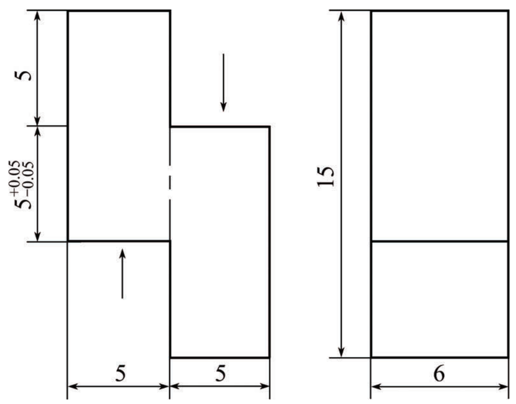

Fig. 2 Geometry of shear test sample (unit: mm)

3 Results

3.1 Morphology of bonding interface

The effect of grain size of primary α phase of Ti−6Al−4V alloy on the morphology of bonding