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Microstructures and interfacial quality of diffusion bonded TC21 titanium alloy joints

LIU Hui-jie, FENG Xiu-li

State Key Laboratory of Advanced Welding Production Technology,
Harbin Institute of Technology, Harbin 150001, China

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Abstract: Diffusion bonding of TC21 titanium alloy was carried out at temperature ranging from 780 °C to 980 °C for 5−90 min. The interfacial bonding ratio, deformation ratio, microstructures and microhardness of the diffusion bonded joints were investigated. Results show that joints with high bonding quality can be obtained when bonded at 880 °C for 15−30 min. The microhardness increases with increasing the bonding temperature, while it has a peak value (HV367) when bonding time is prolonged up to 90 min. Fully equiaxed microstructures, bi-modal microstructures and fully lamellar microstructures were observed when bonded in temperature range of 780−880 °C, at 930 °C or 980 °C, respectively. The volume fraction of α phase first increases and achieves the maximum when bonded at 880 °C for 60 min, and then descended.

Key words: TC21 titanium alloy; diffusion bonding; microstructure; interfacial quality

1 Introduction

TC21 alloy is a new kind of alpha-beta titanium alloy. As it has many properties such as high strength and high fracture toughness, it has a wide application prospect in aviation, aerospace and related industries[1−3]. The research efforts to date [4−6] have mainly been focused on the phase and properties of TC21 titanium alloy under heat treatment. However, little work has been done on the bonding of TC21 titanium alloy to itself or other materials, which is important for its further application.

According to Hall-Patch theory, fine grain sized titanium alloy has superior properties compared with coarse grain one, making it attract a great deal of attention. However, because titanium alloy is very sensitive to welding heat input, it is hard to control the grain growth during welding[7], which will eliminate the strengthening effect of grain refining. Therefore, the effective bonding of fine grain sized TC21 titanium alloy is an important task.

Among the several existing bonding methods for titanium alloys, brazing and diffusion bonding are performed at a low temperature so that the grain growth can be restrained. However, the interfacial reactions between titanium alloys and brazing filler metals are hard to be controlled[8−9]. Compared with brazing, diffusion bonding is a recommended method for bonding of similar titanium alloys[10]. Furthermore, the successful application in diffusion bonding of other titanium alloys provides samples with the bonding of TC21 titanium alloy[11−13]. Therefore, diffusion bonding of fine grain sized TC21 titanium alloy was carried out in the present study, in order to obtain sound joints and reveal the effect of the parameters on the microstructures of the joint.

2 Experimental

The material used in this study was the annealed TC21 titanium alloy with dimensions of 10 mm×10 mm×2 mm. The alloy had an initial average grain size of 7 μm. The chemical composition of TC21 titanium alloy is listed in Table 1 and the initial microstructure is shown in Fig.1. Prior to diffusion bonding, all the surfaces to be bonded were ground to remove the oxidation film and achieve a predetermined degree of roughness with SiC papers having different grit sizes of up to 1 000. Subsequently, all the surfaces were cleaned in acetone.

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Corresponding author: LIU Hui-jie; Tel: +86-451-86413951; E-mail: liuhj@hit.edu.cn
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Table 1 Chemical composition of TC21 titanium alloy (mass fraction, %)

Al	Sn	Zr	Mo	Cr	Nb	Si
6.0~5.5	2.0	2.0	2.5~3.0	1.7	2.0	0.1
Fe	C	N	H	O	Ti	
≤0.15	≤0.08	≤0.05	≤0.015	≤0.15	Bal.	

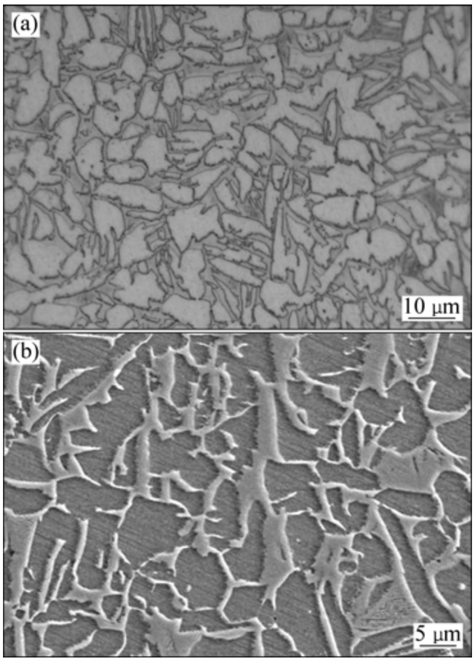

Fig.1 Microstructures of TC21 titanium alloy used: (a) OM; (b) SEM image

Specimens were then assembled and the initial thickness of the specimens (h_0) was measured using a vernier caliper to determine the deformation ratio. A layer of yttrium oxide powder was laid between the specimens and the pressure bars to avoid bonding of them.

Diffusion bonding was carried out in the vacuum furnace (Centorr−M60) with a vacuum degree of 6.6 MPa, under a constant bonding pressure of 10 MPa and at the bonding temperature (θ) ranging from 780 °C to 980 °C for a bonding time (t) of 5−90 min. Once the bonding process was completed, the specimens were cooled to room temperature in the chamber.

After bonding, the thickness of the bonded specimens (h) was measured in order to calculate the deformation ratio (k): $k=(h_0-h)/h_0$. And then the joints were cross-sectioned perpendicular to the interfaces with a spark discharge machine. The cross-sections of these joints were metallographically polished. They were then etched with a mixture of HF (1 mL), HNO_3 (2 mL) and H_2O (47 mL) for 3−5 s. Interfacial behaviors were observed by optical microscope (MPG3) and scanning electron microscope (S−4700), and microhardness was measured using a microhardness tester (HVS−1000), with a test load of 4.9 N for 10 s. Bonding quality was evaluated by the interfacial bonding ratio (η), which is the ratio of the total length of voids at the interface to the total length of the interface.

3 Results and discussion

3.1 Interfacial bonding ratio

Fig.2 shows the interfaces of the joints, which were obtained at different temperatures for 30 min. When