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Influence of pressure on interfacial microstructure evolution and atomic diffusion in the hot-press bonding of Ti-33Al-3V to TC17

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ABSTRACT

Joining of TiAl to Ti alloy is a potential requirement for manufacturing the components with dual properties. In this paper, the hot-press bonding of Ti-33Al-3V to TC17 was implemented at different pressures and the temperature of 850 °C for 10 min with post bond heat treatment. The influence of pressure on interfacial microstructure evolution and atomic diffusion was analyzed in detail. The microstructure observation and phase composition analysis on the bond indicate that the metallurgical bonding of Ti-33Al-3V/TC17 is produced at pressures of 23–50 MPa, and an interfacial zone with a certain width forms between base alloys. A new α_2 (Ti_3Al) phase is generated in the interfacial zone. The influence of pressure on the metallurgical bonding of Ti-33Al-3V/TC17 includes two aspects. One is to promote the void shrinkage in the interfacial zone. The quantitative analysis of voids shows an increase in pressure induces a decrease in amount and size of voids. The highest bonding ratio of 96.3% can be obtained at the pressure of 50 MPa with post bond heat treatment. The second is to promote the atomic diffusion across bond line. The diffusion distances of Ti and Al atoms increase with an increase in pressure and the width of the interfacial zone shows a linear increasing law with the pressure. Moreover, a higher pressure induces a higher increment in atomic diffusion distance and width of the interfacial zone in the post bond heat treatment.

1. Introduction

Joining of dissimilar materials has been a common and crucial requirement in aerospace and hi-tech industries for manufacturing the components with dual properties, like compressors and low-pressure turbine blisks. The intermetallic TiAl alloy composed of γ (TiAl) phase, with an ordered face-centered tetragonal $L1_0$ structure and α_2 (Ti_3Al) with an ordered hexagonal $D0_{19}$ structure, is of engineering interest [1,2]. It is the most promising alternative heat-resistant material for heat-resistant steels and superalloys in aircraft engines, airframes, and automotive engines [3–5], due to its low density (3.8–4.1 $g \cdot cm^{-3}$) and excellent high-temperature capability, including high elastic ratio, good creep, and oxidation resistance. Because of the wide use of Ti alloys, the joining of TiAl to Ti is potential to enlarge the application of TiAl. However, it is difficult to join TiAl to Ti because of their difference in chemical compositions and properties, which may induce high reactivity and residual stress in the fusion welding.

Hot-press bonding is a solid-state joining method to join similar/dissimilar Ti, by which a high quality bond can be obtained because there is no melting of base materials and the disadvantages of fusion welding can be avoided. Although there are numerous reports on similar Ti press/diffusion bonded joints in available literatures [6–12], the number of reports on dissimilar joints between TiAl and Ti is very limited. Çam et al. [13] successfully joined TiAl to Ti-6Al-4V by hot-press bonding and achieved the sound bonds without voids at the temperatures of 850–875 °C and the pressures of 5–8 MPa, for the time of 15–45 min, but the shear strength of bond was lower than that of base alloys. Wang et al. [14] analyzed the microstructure evolution of interface zone in the diffusion bonding of Ti-43Al-9V/Ti-6Al-4V. The interfacial phase sequence was identified as Ti-43Al-9V/γ(TiAl)/B_2/α_2(Ti_3Al)/α(Ti)/Ti-6Al-4V. Some reports show that the sound TiAl/Ti bond with the mechanical properties higher than or similar to those of base alloys can be produced at the temperatures higher than 900 °C and the time of 1–2 h [15,16]. However, the temperatures above 900 °C may cause a phase transformation or grain coarsening of Ti, which will induce a decrease in mechanical properties [17,18].

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Table 1
Chemical compositions of as-received Ti-33Al-3V (wt%).

Al	V	Cr	Ni	O	Ti
32.90	3.24	1.32	0.41	0.048	Bal.

Table 2
Chemical compositions of as-received TC17 (wt%).

Al	Sn	Zr	Mo	Cr	Fe	C	N	H	O	Ti
5.12	2.03	2.10	4.04	3.94	0.10	0.012	0.007	0.007	0.12	Bal.

Pressure is a key parameter to influence the bonding quality. By imposing a large pressure to cause plastic deformation during hot-press bonding, the required time and temperature to obtain high bonding quality will reduce, and the mechanical properties of base alloys will not change. A Ti-17 alloy bond with a high strength and a TiAl/TC17 bond with the microhardness higher than base alloys have been produced at a low temperature and the time of 10 min [19,20]. However, the influence of pressure on the microstructure evolution and atomic diffusion behavior has not been investigated in detail, leading to a lack of understanding with regard to the role of pressure in the metallurgical bonding process of TiAl to Ti.

In this study, different pressures were imposed in the hot-press bonding of TiAl to Ti alloy at the temperature of 850 °C for 10 min. The microstructure characteristics of interfacial zone and the atomic diffusion across bond line were investigated in detail.

2. Experimental

The chemical compositions of Ti-33Al-3V and TC17 used in this study are listed in Tables 1 and 2, respectively. The microstructure of these two alloys is shown in Fig. 1. It can be seen that the microstructure of Ti-33Al-3V consists mainly of γ (TiAl) phases and some α_2 (Ti_3Al) particles, or lamellar colonies, located at γ grain boundaries (Fig. 1a). The microstructure of TC17 consists of equiaxed α grains and β matrix (Fig. 1b).

The specimens for bonding experiments are cylinders with a diameter of 8 mm and a height of 6 mm. The surfaces to bond were ground by SiC papers with grits from 240# to 1500# in sequence, and then cleaned using a KQ-100E ultrasonic cleaning machine. The hot-press bonding of Ti-33Al-3V and TC17 was conducted using a Gleeble 3500 thermal simulation machine. The working chamber was evacuated to a vacuum degree of 5×10^{-2} torr, and then heated to a temperature of 850 °C. Pressures of 23 MPa, 39 MPa, and 50 MPa, were imposed on the bonding specimens, respectively, and then kept for 10 min. After that, the specimens were cooled in air to room temperature. Bonded specimens were cut in half and then the halves were heated at a temperature of 840 °C for 60 min. Sequentially, the heated specimens were cooled in air to room temperature.

The microstructure characteristics of bonded specimens before and after heating were investigated by an optical microscope and

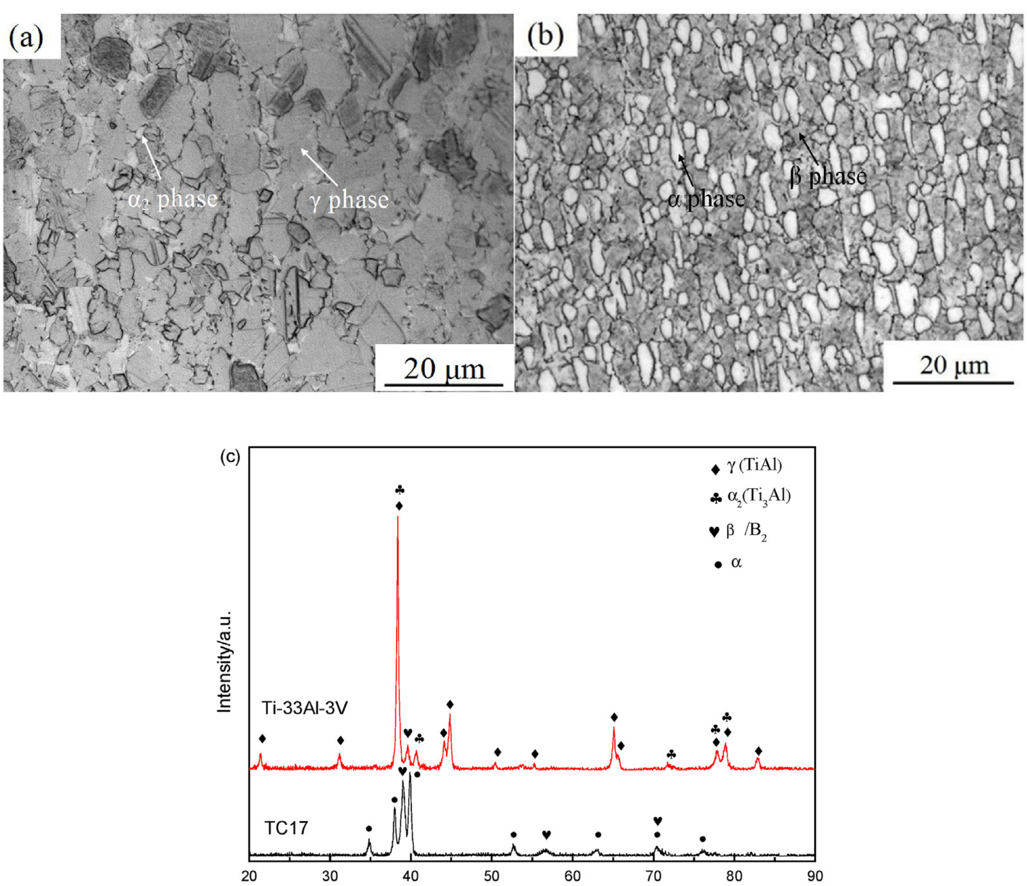

Fig. 1. Microstructure of as-received alloys: (a) Ti-33Al-3V; (b) TC17. (c) XRD patterns of Ti-33Al-3V and TC17.