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Microstructure evolution and mechanical properties of transient liquid phase (TLP) bonded joints of TiAl intermetallics

Tiesong Lin [a], Haixin Li [a,b], Peng He [a,*], Hongmei Wei [a], Liang Li [a], Jicai Feng [a]

[a] State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin 150001, China
[b] Shandong Provincial Key Laboratory of Special Welding Technology, Institute of Oceanographic Instrumentation, Shandong Academy of Sciences, Qingdao 266001, China

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ABSTRACT

TiAl intermetallics were joined by transient liquid phase (TLP) bonding technique using Ti/Ni filler metal. The effects of bonding parameters and composition of filler metal on isothermal solidification and interfacial microstructure of the joints were studied. It was found that a continuous α_2 layer was formed at the joint interface when the bonding temperature was below 1125 °C. This α_2 layer hindered the atom interdiffusion between the TiAl substrate and liquid filler metal, which resulted in a long holding time required for complete isothermal solidification. When the bonding temperature was 1150 °C, no continuous α_2 layer was formed in the joint and the isothermal solidification rate was enhanced. Furthermore, with decreasing of Ni content in the filler metal, the isothermal solidification rate was reduced due to the decrease in dissolution of TiAl substrate into the liquid filler metal. The shear testing results showed that the highest shear strength at ambient temperature (281 MPa) and at high temperature (800 °C) (243 MPa) were achieved, when the joint was bonded at 1150 °C for 5 min.

1. Introduction

TiAl intermetallics are regarded as ideal materials for high temperature application especially in advanced automobile and aero engine components because of their low density and high temperature properties [1,2]. However, its intrinsic poor machinability limits its practical application in some cases. Hence, development of suitable joining process for these kinds of alloys is necessary. Many studies have reported that conventional joining techniques, such as fusion welding [3,4], diffusion bonding [5–7], brazing [8–10] and friction welding [11] can be used to join TiAl intermetallics. However, some problems, such as heat-sensitive cracking and cold crack during fusion welding, high machining precision of the bonding surface for diffusion bonding, low service temperature of the brazing joint, strict requirement of substrate for friction welding, have been encountered during joining TiAl intermetallics by applying these processes. Therefore, TLP bonding technique, which can be used to produce joints with mechanical properties comparable to that of the joined substrate, has been gaining attention for joining TiAl intermetallics.

Some studies have employed TLP bonding to join TiAl intermetallics [12–15]. During TLP bonding process, the filler metals, such as Ti foil combined with Cu, Ni or Fe foils [12], Ti/Ni/Ti and Ti/Ni–Cu/Ti clad-laminated alloy [13,14], mixture composed of Cu powders and atomized TiAl-alloy powders [15], have been used. However, most of the obtained joints were with non-uniform microstructure and little information on the mechanical properties of such joints has been reported. Thus, both microstructural evolution and strength evaluation of the TLP bonded joints of TiAl intermetallics need further study.

In this paper, the TLP bonding technique was employed to join TiAl intermetallics using Ti/Ni filler metal. Although a similar filler metal was used, a very high quality joint with uniform microstructure and high strength (especially high temperature strength) was expected to obtain by adjusting bonding parameters. Therefore, the typical microstructure and the effect of bonding parameters on isothermal solidification and microstructure of the joints were taken into consideration, and the mechanical properties of the joints were also investigated.

2. Experimental

TiAl intermetallics had the nominal composition of Ti-48Al-2Cr-2Nb (at.%). The microstructure of TiAl substrate presented an

* Corresponding author. Tel./fax: +86 451 86402787.
E-mail addresses: hithepeng@hit.edu.cn, hepeng@hit.edu.cn (P. He).

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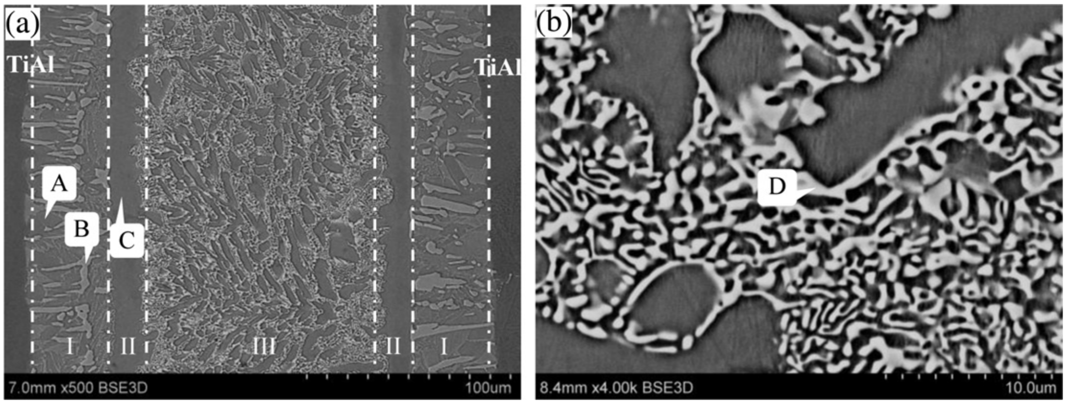

Fig. 1. Typical microstructure of TiAl/Ti/Ni/TiAl joint bonded at 1000 °C for 180 min (a) integral joint; (b) in the middle of the joint.

equiaxed grain structure, which consisted of γ-TiAl. Two sets of TiAl substrates were cut by wire electrodischarge machining: one set (10 mm × 8.0 mm × 2.0 mm) for metallographic observation and another set (5.0 mm × 6.0 mm × 3.0 mm and 15.0 mm × 10.0 mm × 3.0 mm) for shear tests. The mating surfaces were ground with 800 grit SiC abrasive paper and then cleaned ultrasonically in acetone prior to bonding. Two combinations of Ti/Ni foils (Ti-16.5Ni, wt.% and Ti-9Ni, wt.%) were used as filler metal: Ti-16.5Ni (wt.%) consisted of 100 μm Ti foil and 10 μm Ni foil; Ti-9Ni (wt.%) consisted of 200 μm Ti foil and 10 μm Ni foil. The specimens were assembled into a TiAl/Ti/Ni/TiAl type. A small pressure of 1 kPa was applied to keep all the parts proper contact. TLP bonding was performed using a vacuum furnace. A vacuum atmosphere was kept at 4×10^{-3} Pa and the heating rate was 10 °C/min during the TLP bonding. The peak bonding temperature was in the range of 970 °C–1150 °C with a dwell at the peak for 5–240 min.

The microstructure of the products was characterized employing scanning electron microscopy (SEM, S-4700) with energy dispersive X-ray spectroscopy (EDS; TN-4700; the accelerating voltage was 20 kV) and X-ray diffraction (XRD; JDX-3530M; Cu-K_a). The shear tests were performed at a constant speed of 1 mm/min by an electro-mechanical universal material testing machine (INSTRON 1186), which was produced by Instron Limited, both at ambient temperature and at high temperature (800 °C). At least five specimens were used for each experimental condition to average the joint strength. The fracture surfaces of joints after shear test were also observed by SEM and EDS.

3. Results and discussion

3.1. Typical microstructure of the TiAl joints

Fig. 1 shows the typical interfacial microstructure of joint bonded with Ti-16.5Ni (wt.%) filler metal at 1000 °C for 180 min. The interfacial microstructure displayed a symmetrical characteristic and comprised three reaction layers, as shown in Fig. 1(a): Layer I (reaction layer adjacent to TiAl substrate), Layer II (a continuous dark grey reaction layer) and Layer III (a reaction layer in the middle area). For layer III, as shown in Fig. 1(b), some fine white precipitates distributed on the dark grey substrate. The EDS results of the major elements at each point in Fig. 1 are shown in Table 1. According to the EDS results, the dark grey phases in layer I (marked by A) and in layer II (marked by C) were mainly composed of Ti and Al, and the proportions of Ti and Al were about 1.5:1 and 2.4:1, respectively. According to the Ti–Al binary phase diagram [16], layer I and layer II were demonstrated to be Ti_3Al (α_2) + TiAl (γ) and α_2 phase, respectively. The contents of Ti (33.1 at.%), Al (42.6 at.%) and Ni (21.3 at.%) were detected in point B, which indicated that the grey phase in layer I might be Al_3NiTi_2 (τ_3) phase (from the Ti–Al–Ni ternary phase diagram [17]). The content of 57.5 at.% Ti and 28.8 at.% Ni were detected in point D, which indicated the white precipitates in layer III was Ti_2Ni phase.

To further identify the interfacial products of the joint, X-ray diffraction of fracture surface of the joints bonded in the same conditions with those in Fig. 1 was performed. The results in Fig. 2 showed that a small number of τ_3 phase and a large number of α_2 and Ti_2Ni phase were detected. It can be seen that the results were strong agreement with the analysis in Fig. 1. Based on the microstructure of joints and previous studies in Ref. [18–20], the process of phases formation in this study could be elaborated as follows: Firstly, when the filler metal melted completely, the liquid (L) filler metal reacted with the solid (S) γ-TiAl substrate, the α_2 phase in layer I was formed ($TiAl_{(S)} + 2Ti_{(L)} \rightarrow Ti_3Al_{(S)}$). Since almost no Ni dissolved in α_2 phase, most of the Ni segregated and combined with

Table 1
EDS results of chemical compositions at each spot in Fig. 1 (at.%).

Zone	Ti	Al	Nb	Cr	Ni	Possible phase
A zone	55.59	37.36	1.73	1.69	3.62	$\alpha_2 + \gamma$
B zone	33.10	42.57	1.39	1.64	21.30	τ_3
C zone	68.80	29.05	0.81	0.60	0.74	α_2
D zone	57.47	11.28	0.48	1.96	28.81	Ti_2Ni

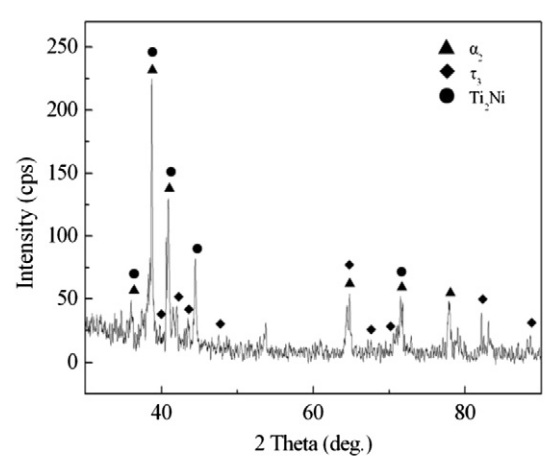

Fig. 2. XRD results of fracture surface of joint after shear test.