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Effect of brazing temperature and brazing time on the microstructure and tensile strength of TiAl-based alloy joints with Ti-Zr-Cu-Ni amorphous alloy as filler metal

Y.S. Cai[a,b], R.C. Liu[a], Z.W. Zhu[a], Y.Y. Cui[a,*], R. Yang[a]

[a] Institute of Metal Research, Chinese Academy of Sciences, 72 Wenhua Road, Shenyang 110016, PR China
[b] University of Chinese Academy of Sciences, Beijing 100049, PR China

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ABSTRACT

An amorphous Ti-37.5Zr-15Cu-15Ni (wt.%) ribbon fabricated by vacuum arc remelting and rapid solidification was used as filler metal to vacuum braze TiAl alloy (Ti-45Al-2Mn-2Nb-1B (at.%)). The effects of brazing temperature and time on the microstructure and strength of the joints were investigated in details. The typical brazed joint major consisted of three zones and the brazed joints mainly consisted of α_2-Ti_3Al phase, α-Ti phase and $(Ti, Zr)_2(Cu, Ni)$ phase. When the brazing temperature varied from 910 °C to 1010 °C for 30 min, the tensile strength of the joint first increased and then decreased. With increasing the brazing time, the tensile strength of the joint increased. The maximum room temperature tensile strength was 468 MPa when the specimen was brazed at 930 °C for 60 min. All the fracture surfaces assumed typical brittle cleavage fracture characteristic. The fracture path varied with the brazing parameter and cracks preferred to initiate at $(Ti, Zr)_2(Cu, Ni)$ phase and propagation path were mainly determined by the content and distribution of α-Ti phase and $(Ti, Zr)_2(Cu, Ni)$ phase.

1. Introduction

γ-TiAl alloys is a kind of high-temperature structural materials and it have been considered as the most promising alternative materials to substitute nickel-based superalloys in the automobile field and aerospace field for significant weight saving [1–4]. Compared with traditional titanium alloys, γ-TiAl alloys possess lower density, higher specific strength and outstanding creep and oxidation resistance at elevated temperature. With the developing of research, part of alloys have been used in engine of aeroplane and automobile [4,5]. However, the practical utilization of γ-TiAl alloys is delayed because of the intrinsic properties, such as brittleness and poor workability [6,7]. Therefore, γ-TiAl alloys welding also become very difficulty.

According to the literature report, γ-TiAl alloys welding can be divided into two types: fusion welding and solid state welding, such as electron beam welding [8], laser beam welding [9,10], friction welding [11], diffusion bonding [12] and brazing [13]. Among those methods, brazing as the most feasible and economical bonding technique, has received special attention in joining γ-TiAl alloys.

Filler metal's properties play an important role in brazing γ-TiAl alloys. Although Ag-based and Al-based filler metals can braze γ-TiAl alloys successfully, these filler metals suffer from insufficient bonding strength, weak corrosion and oxidation resistance, and low creep strength [14–16]. Compare with Ag-based and Al-based filler metals, Ti-based filler has good compatibility on γ-TiAl alloys surface. In addition, Ti-based filler joints represent high bonding strength and good corrosion resistance [17,18]. According to the literature report, Ti-Zr-Cu-Ni filler was used to braze γ-TiAl alloys widely. There are many researches about brazing γ-TiAl alloys with eutectic filler, such as Song et al. [7] studied the brazing high Nb containing TiAl alloy with TiNi-Nb eutectic alloy. Compare with eutectic filler, amorphous filler possesses lower brazing temperature, higher atomic diffusion, higher surface reaction and superior wettability [19,20]. However, there are seldom researches about using amorphous Ti-Zr-Cu-Ni filler to braze γ-TiAl alloys.

The present work used amorphous Ti-Zr-Cu-Ni filler to braze γ-TiAl alloys, and the emphasis is placed on the microstructure and mechanical properties of the brazed joints with different brazing temperature and time.

* Corresponding author.
E-mail address: yycui@imr.ac.cn (Y.Y. Cui).

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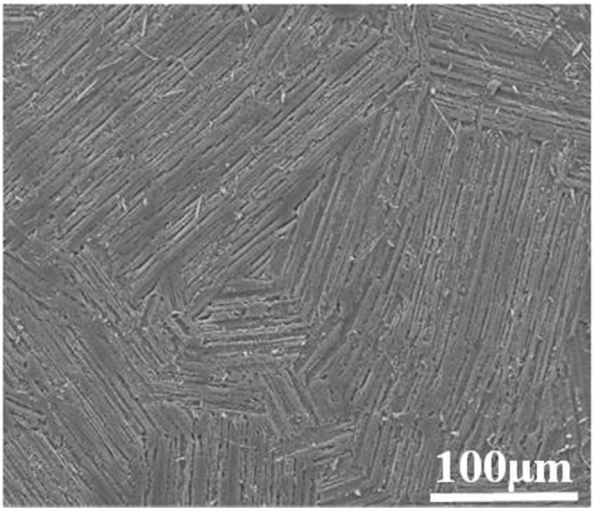

Fig. 1. Microstructure of the 45XD alloy.

2. Experimental procedure

2.1. Materials

The base-metal was γ-TiAl alloy with nominal composition of Ti-45Al-2Mn-2Nb-1B (at.%, called as 45XD). The typical microstructure was fully lamellar, as shown in Fig. 1. The filler metal was Ti-37.5Zr-15Cu-15Ni (wt.%) amorphous ribbon and its thickness was about 40 μm, corresponding XRD pattern was shown in the Fig. 2. The XRD pattern consists of broad diffuse diffraction peak at a diffraction angle 2θ of about 40°. No crystallization diffraction peaks can be found, indicating that the filler foil is in amorphous state. The thermal behavior of filler metal was measured by differential scanning calorimetry (DSC) with a heating rate of 10 °C/min, as shown in Fig. 3. From the DSC curve we know that the liquidus temperature (T_l, T_1 was the Ti-Zr-Cu-Ni amorphous filler melting temperature) and solidus temperature (T_s) of filler metal were 879 °C and 840 °C, respectively. On account of the ambiguity in melting temperature determination, we assumed T_l to represent the melting temperature. Therefore, the brazing temperature was chosen varied from 910 °C to 1010 °C, which was higher than filler metal melting temperature 31 °C–131 °C. Fig. 4(a) shows the low magnification microstructure of filler foil after heat treated at 910 °C for 30 min. It is clearly seen that there were many strip and blocky precipitations in the substrate. From the high magnification microstructure (Fig. 4(b)), the filler foil consisted of four phases after heat treatment: strip and blocky precipitated phase and two kind of different contrast

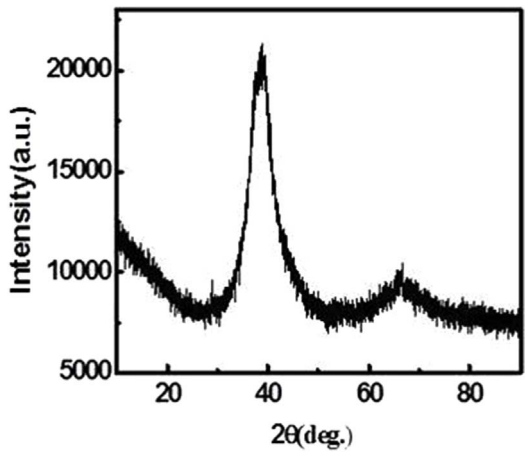

Fig. 2. XRD pattern of the Ti-Zr-Cu-Ni filler foil.

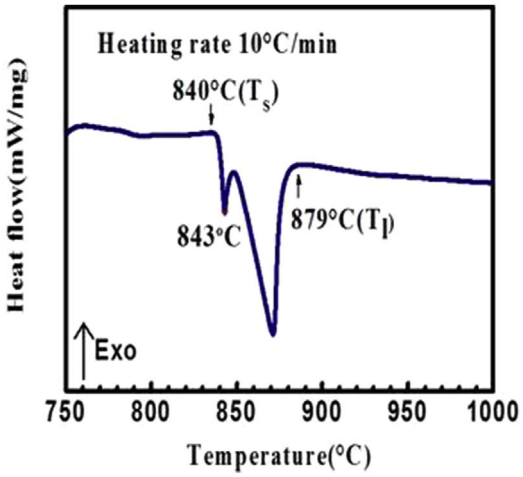

Fig. 3. DSC curve of the filler foil.

substrate phases. Table 1 shows the EDS analysis results of all spots in Fig. 4(b). According to the elemental contents, Ti(Zr)-Cu and Ti(Zr)-Ni binary alloy phase diagram [21], the amorphous Ti-Zr-Cu-Ni filler foil consisted of α-Ti phase and (Ti, Zr)$_2$(Cu, Ni) phase after heat treatment.

2.2. Brazing

Prior to brazing, in order to remove oxidation contamination, the joint surfaces of the 45XD specimens and the Ti-37.5Zr-15Cu-15Ni filler metal were polished. After polishing, the filler metal was successively ground on SiC grit paper to 30 μm. And then all samples were cleaned by ultrasonical for 10 min in the bath of petroleum ether and alcohol. Subsequently, the filler foil was sandwiched between two 45XD alloy specimens with a specialized clamp, as shown in Fig. 5. After that, the assembly was brazed in vacuum furnace with a vacuum of 5×10^{-3} Pa to 1×10^{-4} Pa. The schematic of brazing process is shown in Fig. 6, the first step was heating the brazing couple to 800 °C with a rate of 10 °C/min, and then held for 10 min at this temperature. After that, with a rapid rate of 15 °C/min, the furnace was heated to brazing temperature. The brazing temperature varied from 910 °C to 1010 °C with holding time was 5–60 min. At last, the furnace was cooled down to room temperature.

2.3. Microstructure observation and mechanical testing

After brazing, the joints were longitudinally cut, and then grinded (150 #, 800 #, 2000 # SiC grit paper) and polished. All the metallographic specimens were etched by Kroll's reagent. The room temperature tensile strength was tested using a Shimadzu AG-100KN universal testing machine with a constant loading rate of 1 mm/min, each condition with at least three specimens. Scanning electron microscopy (SEM) was used to characterize the microstructures of joints brazed, the fracture surfaces and fracture paths after tensile test. Energy dispersive X-ray spectroscopy (EDS) was used to inspect the element distribution in the brazed joint, amorphous filler metal and interfacial compound on the fracture surface. X-ray diffraction was used to verify the phase constitution on the fracture surfaces.

3. Results and discussion

3.1. Interfacial microstructure of the brazed joint

Fig. 7 shows the representative interfacial microstructure of the joint brazed at 930 °C for 30 min, no cracks and pores was found, meaning the brazed joint was soundly bonded. Based on the microstructural morphology and the chemical composition, the whole brazed