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Vacuum brazing of C_f/β–spodumene composites and Ti–6Al–4 V alloy using Ag–Cu filler metal

X.G. Song[a,b], Y.X. Zhao[b], H.W. Niu[a], J.H. Liu[b], D. Liu[a,*], L. Xia[c], H. Bian[b], J.C. Feng[a,b]

[a] Shandong Provincial Key Laboratory of Special Welding Technology, Harbin Institute of Technology at Weihai, Weihai 264209, China
[b] State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin 150001, China
[c] School of Materials Science and Engineering, Harbin Institute of Technology at Weihai, Weihai 264209, China

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ABSTRACT

Interfacial microstructure and mechanical properties of Ti–6Al–4 V/C_f/β–spodumene composites joints brazed by Ag–Cu eutectic brazing filler were investigated. The effects of brazing temperature and holding time on the interfacial microstructure and mechanical properties of Ti–6Al–4 V/C_f/β–spodumene composites joints were studied. The result indicated that the typical interfacial microstructure of the joint was Ti–6Al–4 V/Ti_2Cu + α-Ti (s,s)/Ti_2Cu/TiCu/Ag (s,s)/Cu (s,s)/Ti_2Cu_3/$TiSi_2$ + TiC/C_f/β–spodumene composites. The thickness of the diffusion layer, Ti_2Cu_3 layer, and reaction layer on the interface of C_f/β–spodumene composites increased with the brazing temperature or holding time increasing, meanwhile, the thickness of Ti–Cu layers decreased. The diffusion of Ti in brazing seam, which was significantly determined by the brazing temperature and holding time, was a decisive factor on the interfacial microstructure and mechanical properties of brazed joints. The optimal shear strength of joint brazed at 880 °C for 10 min was 33.5 MPa. Further raising the brazing temperature or extending the holding time would reduce the shear strength of joints. Brazing specimens brazed at 880 °C and 910 °C for 10 min broke in form of cleavage fracture after shearing test. Moreover, the formation of excessive thickness of $TiSi_2$ + TiC layer or Ti_3Cu_4 reaction layer was harmful to the mechanical property of the joint.

1. Introduction

With very low thermal expansion coefficient (CTE) and low density, as well as excellent toughness, high specific strength and stiffness, carbon fiber reinforcedβ–spodumene matrix composites (C_f/β–spodumene) have become a promising structure material for the precision optical devices, especially in the applications requiring dimensional stability and size precision [1–3]. Ti–6Al–4 V alloy can also be widely used as a stable structure, owing to its excellent properties such as high strength-to-weight ratio and excellent corrosion resistance [4]. To enhance their potential applications in practical structures, it is necessary to joint C_f/β–spodumene composites and Ti–6Al–4 V alloy together. Brazing is widely used in joining a wide range of materials due to its promising result. Joining ceramic to metals or itself, and joining intermetallic to metals or other dissimilar metals are the foremost brazing joints. Thus, brazing can be applied to join C_f/β–spodumene composites and Ti–6Al–4 V alloy. The final properties of the brazed joint were usually determined by the interaction of the filler metals and substrates during the brazing process. The wettability of brazing filler on composites surfaces was a common problem in brazing composites and metals [5–8,11]. Active brazing has improved wettability of brazing filler on composites surface. The elements of Ti, Zr, Hf and V are sometimes added to brazing alloy in small quantities to improve the wettability on composites. The majority studies of carbon fiber reinforced composites brazing have used active brazing alloys based on the Ag–Cu eutectic filler system contained a certain amounts of Ti. Previous studies have elucidated, Ag–Cu–Ti filler foil [6,8,11] and Ag–Cu–Ti + nano–Al_2O_3 mixed powder [7] were used to join carbon fiber reinforced composites. However, Ag–Cu eutectic, which melt at a low temperature (780 °C) and spreading well during melting, has been used for brazing carbon fiber reinforced composites to titanium alloy [9–10,12–15]. Although this filler hardly wet the composites for lacking of active element, joining carbon fiber reinforced composites with titanium alloy was possible by adopting the inactive Ag–Cu filler which gained active Ti from the dissolution and diffusion of titanium alloy.

Identifying the chemical reactions producing at the interface and understanding the mechanisms of these reactions can help product the joint with desired properties. Microstructural and chemical analyses of the brazing seam were effective measures by using techniques at a submicron length scale, such as transmission electron microscopy

* Corresponding author.
E-mail address: liuduo0376@163.com (D. Liu).

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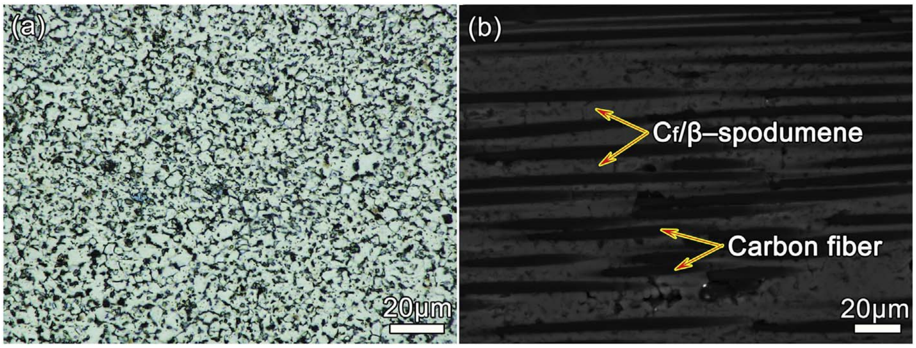

Fig. 1. Microstructures of the base metal. (a) Metallographic figure of Ti–6Al–4 V alloy, (b) BSE image of C_f/β–spodumene composites.

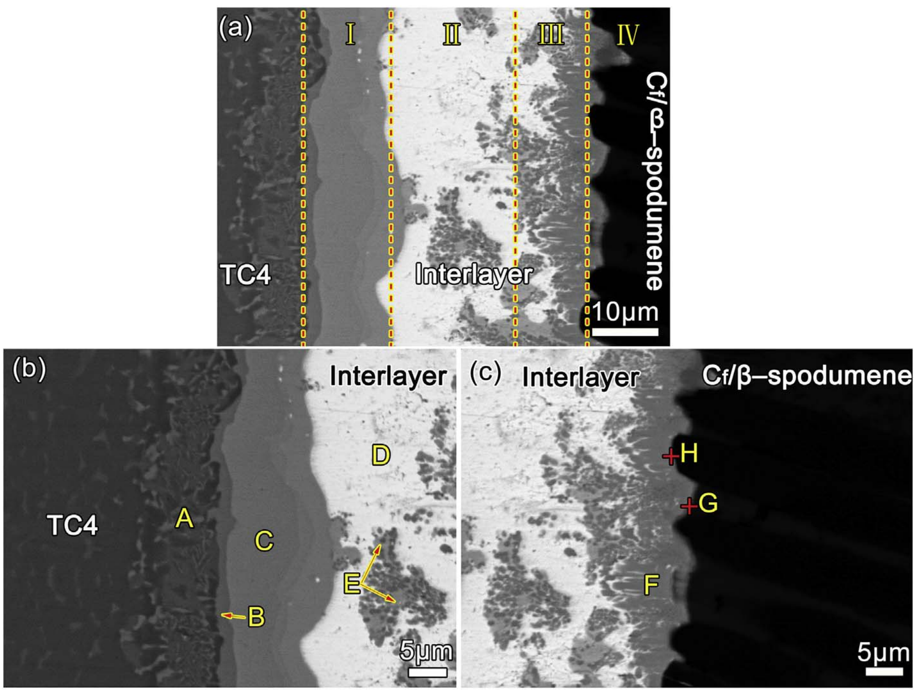

Fig. 2. Interfacial microstructure of Ti–6Al–4 V/Ag–Cu/C_f/β–spodumene composites joint brazed at 880 °C for 10 min. (a) The whole joint, and high magnification BSE images of (b) C_f/β–spodumene composites side and (c) Ti–6Al–4 V side.

(TEM), to research the reaction during brazing. Therefore, the microstructure and phase relationship during brazing C_f/β–spodumene composites to Ti–6Al–4 V alloy by Ag–28Cu (wt%) eutectic alloy were investigated in-depth in this study. The mechanisms of the interfacial reactions also have been clarified in the present study. The effects of brazing process parameters on interfacial microstructure and mechanical properties of the joints were discussed in detail.

2. Experimental Procedures

The substrate materials used in the experiment were C_f/β–spodumene composites and Ti–6Al–4 V alloy. C_f/β–spodumene composites were cut into cubic block with a size of 5 mm × 5 mm × 5 mm for microstructure examination and shear testing using diamond cutting machine. Ti–6Al–4 V alloy was cut into rectangular block with a size of 10 mm × 10 mm × 3 mm for microstructure examination and 10 mm × 25 mm × 3 mm for shear testing by wire-electrode cutting machining. Ag–28Cu (wt%) eutectic alloy foil of 100 μm thick foil was used in this work. The microstructures of the substrate materials are illustrated in Fig. 1(a) and (b). The surfaces of the substrates to be brazed were sanded with 1000 grit SiC papers and then C_f/β–spodumene composites, Ti–6Al–4 V alloy and Ag–Cu foils were soaked and cleaned in acetone under ultrasonic for 20 min.

The Ag–Cu filler foil was placed between Ti–6Al–4 V alloy and C_f/β–spodumene composites in sandwich form and a certain pressure was applied by the graphite blocks to ensure the brazing surfaces contact closely. The furnace was maintained at about 1.5×10^{-3} Pa vacuum and a thermocouple spot close to the C_f/β–spodumene composites/Ti–6Al–4 V interface to monitor the temperature of the brazing sample. During brazing, in order to ensure temperature consistency in the vacuum furnace, the assembled joints were first heated to 740 °C at a rate of 20 °C/min, and held for 10 min. Then the temperature was continuously increased to specified temperature (850–920 °C) at a rate of 10 °C/min and held for required time (0–20 min). Finally, the assembled joints were cooled down to 300 °C at a rate of 5 °C/min and then cooling inside the furnace to room temperature.

The interfacial microstructure of brazed joints was characterized by scanning electron microscopy (SEM), and the energy dispersive spectrometer (EDS). The metallographic phases of reaction layers were identified by examining C_f/β–spodumene composites/Ti–6Al–4 V alloy joint using X-ray diffraction (XRD). A transmission electron microscopy (TEM) equipped with EDS was used to characterize the interfacial microstructure of the brazed joints at submicron scale. The selected area diffraction pattern (SADP) of TEM was also adopted to characterize the crystal structures of the reaction products. The shearing tests were carried out by a universal testing machine at a steady speed of 0.5 mm/min. A schematic of shearing test was same as what reported in Ref. [8,11]. At least five samples were tested for each set of experimental data, to obtain the average shear strength of brazed joints. Additionally, the fracture of brazed joints after shearing test was investigated by SEM