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Effect of processing parameters on the formation of C_f/LAS composites/Ag—Cu—Ti/TC4 brazed joint

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ABSTRACT

C_f/LAS composites were successfully jointed to TC4 alloy with Ag—Cu—Ti filler by vacuum brazing. The interfacial microstructure of TC4/C_f/LAS composites joints was characterized by employing scanning electron microscope (SEM), energy dispersive spectrometer (EDS), X-diffraction (XRD) and transmission electron microscopy (TEM). The determination of the thin interfacial reaction layer ($TiSi_2$ + TiC layer) was realized by TEM. The effect of holding time on the interfacial microstructure and shear strength were investigated. With the increasing holding time, the thickness of diffusion layer, Ti_3Cu_4 layer, and $TiSi_2$ + TiC layer increased obviously, on the contrary, that of Ti—Cu intermetallic compound layers decreased gradually. Besides, blocky Ti_3Cu_4 phase was coarsened when the joint was brazed at 890 °C for 20 min, which deteriorated the mechanical properties of the joint dramatically. The interfacial evolution of TC4/C_f/LAS composites joint and the formation of $TiSi_2$, TiC, Ti_3Cu_4, TiCu and Ti_2Cu phases were expounded. The maximum shear strength of 26.4 MPa was obtained when brazed at 890 °C for 10 min.

1. Introduction

Unidirectional carbon fiber reinforced spodumene composites (C_f/LAS composites) have demonstrated a wide range of attributes, including high strength, high stiffness, excellent toughness, unique wear resistance, and environmental stability for structural application [1]. Especially, their ultra-low or even negative coefficient of thermal expansion (CTE) and their thermal stability and resistance to thermal shock have contributed to many applications in domestic cookware, precision optical devices and turbine heat exchangers [2]. In addition to these applications, C_f/LAS composites had a potential to be used as material suitable for packaging of large-scale integrated circuits due to its low dielectric constant and low thermal expansion [3]. However, the applications of C_f/LAS composites as high performance materials are severely hindered by the characters of brittleness and difficult machining in the process of fabricating into complicated structural components. Practical applications usually require C_f/LAS composites to be jointed to refractory metals such as Ti-6Al-4V (TC4) alloy.

It is very difficult to use bolting, riveting, bonding adhesives, fusion welding due to the properties and the application environment of C_f/LAS composites. Vacuum brazing is the most suitable way to joint C_f/LAS composites and TC4 alloy. Ag—Cu—Ti active brazing filler metal has been widely used to bond composites, owing to its good wettability on composite surface and suitable melting point, which does not degrade the base material during the brazing process. Zhao et al. [4] joined the Si_3N_4 ceramic tube to TC4 alloy with the nano-Si_3N_4 reinforced AgCu composites filler and a layered microstructure was formed at the interface of the joint. Niu et al. [5] brazed Al_2O_3 ceramic to TiAl alloy using Ag—Cu—Ti filler metal. Wang et al. [6] studied the active brazing of SiO_2-BN ceramic and Invar alloy with Ag—Cu—Ti + TiH_2 + BN composite filler. In these researches, the active Ti in the filler played an important role in wetting the ceramic substrate. Little literature is available for brazing C_f/LAS composites to TC4 alloy. Thus, brazing of other carbon fiber reinforced composites is referenced, such as C/C composite [7–14] and C_f/SiC composite [15–23]. In our previous study [24], TC4/C_f/LAS composites joints could be obtained by using Ag—Cu—Ti active filler metal. The effects of brazing temperature on the microstructure and the mechanical properties of the joints were investigated in detail. But the determination of the thin interface reaction layer was not realized by transmission electron microscopy (TEM). And the microstructural and chemical analyses of the brazing zone at a submicron length scale were rarely attempted in most of the references. The lack of TEM studies may be attributed to the difficulty in specimen preparation due to brittleness of the joints, differential thinning on either side of the joint, and the low success rate of achieving electron transparency in the regions around the joint interface [25].

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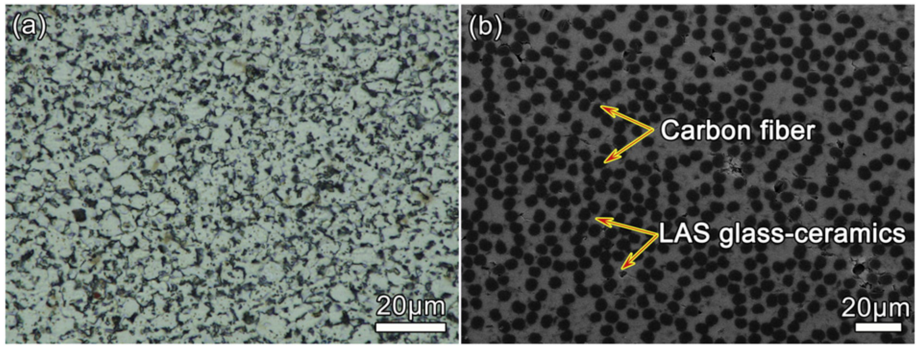

Fig. 1. Microstructures of the substrate materials. (a) TC4 alloy, (b) C_f/LAS composites.

In the present work, commercially available Ag—Cu—Ti active brazing filler metal was used to braze C_f/LAS composites to TC4 alloy. A transmission electron microscope equipped with energy dispersive spectrometer (TEM/EDS) was introduced to accurately analyze the reaction products at the C_f/LAS composites/brazing seam interface. The effect of holding time on the microstructure and the shear strength of the joints were investigated as well. Furthermore, the microstructural evolution of the C_f/LAS composites/Ag—Cu—Ti/TC4 joint was also expounded.

2. Materials and Experimental Procedures

Unidirectional carbon fiber reinforced spodumene composites (C_f/LAS composites) were provided by Harbin Institute of Technology at Weihai, China. It was fabricated by sol-gel process and hot pressing technique. The porosity and density of C_f/LAS composites were approximately 0.7% and 2.06 g/m^3, respectively. C_f/LAS composites and Ti-6Al-4V (TC4) alloy were brazed with a commercially obtained Ag-21Cu-4.5Ti (wt.%) active brazing filler metal (100 μm thick) in the experiment. The microstructures of TC4 alloy and C_f/LAS composites used in the experiments are shown in Fig. 1(a) and (b), respectively.

Rectangular pieces of size 5 mm × 5 mm × 5 mm and 10 mm × 20 mm × 3 mm were cut from the bulks of C_f/LAS composites and TC4 alloy, respectively. The surfaces to be joined of both materials were ground by 1000 grit silicon carbide paper. The surface of Ag—Cu—Ti foil was ground using 1200 grit emery paper to remove the surface-oxide layer. Prior to brazing, all the components were cleaned ultrasonically for 20 min in acetone and dried by air blowing.

Sandwich-type brazing assembly of the C_f/LAS composites and TC4 alloy was prepared by aligning them with Ag—Cu—Ti foil between the two base materials. The assembly was carefully placed into the vacuum furnace. The vacuum of the furnace chamber was maintained at about 1.5×10^{-3} Pa throughout the brazing operation. Additional thermocouple, with its tip placed very close to the C_f/LAS/TC4 interface, was used to monitor exact temperature of the assembly. The whole brazing process can be divided into three steps. Firstly, the brazing assemblies were heated to 740 °C at a rate of 20 °C/min and held for 10 min. Secondly, the brazing temperature was selected as 890 °C with a dwell time of 0–20 min, while the holding time interval was 5 min. Thirdly, the cooling rate of the couples was initially 5 °C/min till 300 °C and the joints were finally cooled down to room temperature in the vacuum furnace.

The brazed specimens for metallographic observation were cross-sectioned perpendicular to the brazed interface. The microstructure of the brazed joints was characterized by scanning electron microscope (SEM) equipped with energy dispersive spectrometer (EDS). Furthermore the brazing seam was investigated by X-ray diffraction (XRD) spectrometer equipped with Cu-Kα radiation in order to identify the interfacial phases accurately. Meanwhile, the microstructure of reaction products at the C_f/LAS/brazing seam interface was observed by a transmission electron microscopy (TEM), which is equipped with EDS. The specimens for TEM investigation were performed by a combination of polishing and ion milling system (PIPS, Model 695 Gatan, USA). The composition and crystal structures of reaction products were characterized by EDS and selected area diffraction pattern (SADP) of TEM, respectively. A schematic for shear test could be seen in Ref. [24]. In order to identify the phases on the fracture, the fracture surfaces were analyzed by SEM equipped with EDS.

3. Results and Discussion

3.1. Microstructure of C_f/LAS Composites/TC4 Joint

Fig. 2 shows the interfacial microstructure and the EDS live map of C_f/LAS composites/TC4 joint brazed at 890 °C for 10 min. The EDS chemical compositions of each phase in Fig. 2(a) are listed in Table 1. During brazing, intensive interaction including dissolution, reaction, and interdiffusion occurred at the interface in the joints.

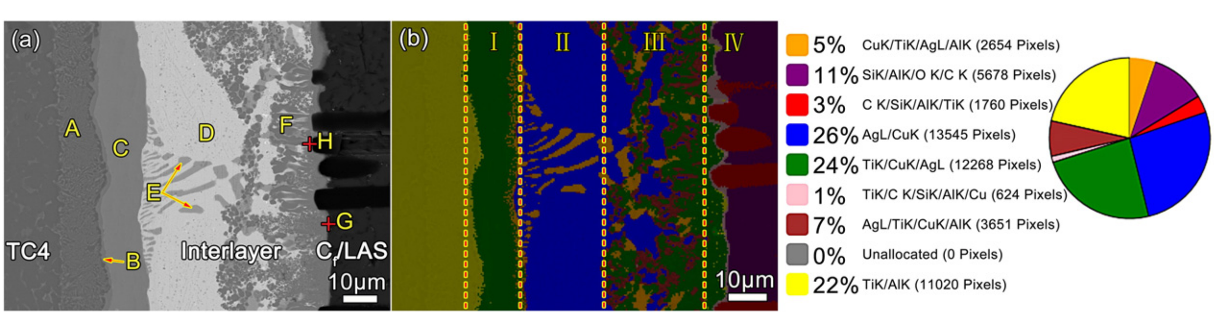

Fig. 2. Interfacial microstructure and the EDS map of the joints brazed at 890 °C for 10 min. (a) TC4/AgCuTi/C_f/LAS composites joint, (b) EDS live map of the joint.