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Reaction-composite brazing of carbon fiber reinforced SiC composite and TC4 alloy using Ag–Cu–Ti–(Ti+C) mixed powder

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ABSTRACT

Carbon fiber reinforced SiC (C_f/SiC) was successfully joined to TC4 alloy with Ag–Cu–Ti–(Ti+C) mixed powder by proper parameters. The interfacial microstructure was investigated by scanning electron microscopy (SEM), energy dispersive spectrometry (EDS) and X-ray diffraction (XRD). The mechanical properties of the brazed joints were measured by a mechanical testing machine. The results show that the Ti element in the interlayer can react with the brazed composite, the brazed joints mainly consist of TiC, Ti_3SiC_2, Ti_5Si_3, Ag, residual graphite, TiCu, Ti_3Cu_4 and Ti_2Cu reaction products, and the performed joints have dense bonding layers reinforced by residual graphite and in situ synthesized TiC from reaction between C and Ti in the filler materials. The TiC particulates obviously relax the thermal stress in the heterogeneous joint resulting in an increase in shear strengths of the brazed joint. The maximum shear strengths of the brazed joints at room temperature, 500 °C and 800 °C are 145 MPa, 70 MPa and 39 MPa, respectively. The shear strengths of the joints are remarkably higher than the optimal of the joints brazed with Ag–Cu–Ti.

1. Introduction

Carbon fiber reinforced SiC (C_f/SiC) ceramic matrix composites, which exhibit an excellent resistance to wear and oxidation at high temperature, have been considered as a desirable high temperature structural material in aeronautical turbines and advanced rocket propulsion thrust chambers [1–4]. Due to the brittle nature of C_f/SiC composite, it is difficult to be manufactured into workpieces with large dimensions and complex shapes, which will increase the preparation cost. Consequently, in many high-temperature applications of C/SiC, there is a requirement to join it to other materials, including metals. Therefore, the development of joining techniques is very important for joining of C_f/SiC composite to itself or to metal, especially Ti alloy.

Significant differences in chemical and physical properties between C_f/SiC composite and metal make it difficult to find an effective joining method. There are two main problems in joining C_f/SiC composite to metal: one is the poor wettability of C_f/SiC composite by most metals and alloys; the other is the mismatch in the coefficient of thermal expansion (CTE) between the ceramic and metal, which would result in high critical residual stress and degrade the quality of the joints. Compared with other joining methods, including diffusion bonding [5,6], brazing is becoming an effective method to join ceramic to itself or to metals because of the simplicity, lower cost investment and so on. So far, brazing [7,8] has been reported for joining C_f/SiC composite.

Owing to the good wettability on ceramic surface and lower melting point, which does not degrade the base material during the process, Ag–Cu–Ti active brazing filler metal has been widely used to bond C_f/SiC composite and the joint strength obtained is higher than that of composite brazed with Ni based or Ti based filler metal. The problem of the coefficient of thermal expansion (CTE) mismatch may be alleviated by the addition of low CTE material (particles or fibers, such as W, Al_2O_3, SiC,) in the brazing alloy [9–13]. However, the low CTE material must be well matched with the brazing alloy, such as reliable wettability with brazing alloy, chemical stability, easy dispersibility in the filler and so on.

In order to solve above problems and obtain excellent joints, a new joining method called reaction-composite brazing was developed. The low CTE material was in situ synthesized by reaction during the brazing process, which has greater reinforcing effect, uniform distribution and cohesion with base materials. In this paper, Ag–Cu–Ti–(Ti+C) mixed powder was used to join C_f/SiC composite to TC4 alloy and the microstructures of the brazed joints and the interface evolution mechanism of the C_f/SiC composite/Ag–Cu–Ti+(Ti+C)/TC4 joints were analyzed. In addition, the effects of brazing parameters on the mechanical properties during brazing process were investigated.

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2. Experiment procedure

In this study, the materials to be joined were 3D-C_f/SiC composite and TC4 (Ti–6Al–4V wt%) alloy. The microstructure of 3D-C_f/SiC composite is shown in Fig. 1.

The C_f/SiC composite is prepared by the Polymer Infiltration Pyrolysis with the combination of Chemical Vapor Deposition; its density is 1.7–1.8 g/cm^3, its porosity is 10–15 vol%, and the carbon fiber volume fraction is 45–50%. The main mechanical properties at room temperature are shown in Table 1. The C_f/SiC composite and TC4 alloy were cut into blocks 5 mm × 5 mm × 5 mm and 12 mm × 12 mm × 3 mm, respectively. The surface to be joined was ground by 400 grit silicon carbide paper for the C_f/SiC composite and 60 grit for the TC4 alloy. Then they were cleaned in ethanol and dried at 50 °C.

The brazing filler material used in the experiments was Ag–Cu–Ti–(Ti+C) mixed powder. The active filler alloy powder was 67.6Ag–26.4Cu–6Ti (wt%) with the particle size of 320 mesh. The particle size of Ti and C was 300 mesh and 7 μm, respectively.

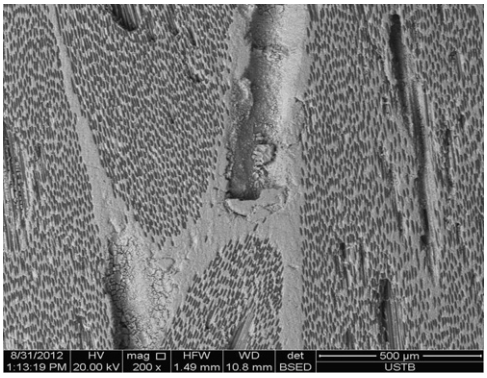

Fig. 1. Microstructure of C_f/SiC composite.

Table 1
Main mechanical properties of C_f/SiC composites at room temperature.

Three-point flexural strength (MPa)	Elastic modulus (GPa) EXEY/EZ	Coefficient of thermal expansion (10^{-6} °C^{-1}) ALPX/ALPZ	Poisson ratio
400	174.82/18.23	3.1/3.0	0.3

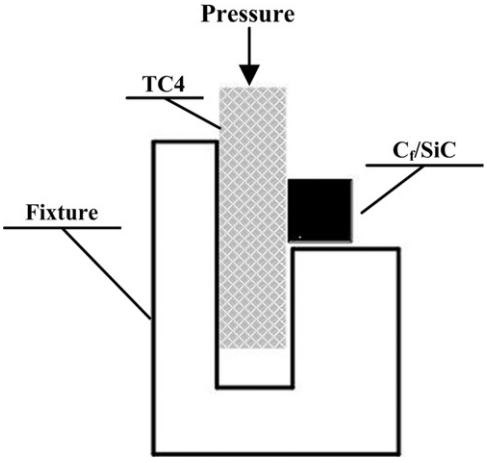

Fig. 2. Schematic of the shear test of the joint sample.

According to the density transformation, Ti and C powders were added to in situ synthesize 5, 15, 25 vol% TiC in the brazing material after brazing. The purity of the powder mentioned above reaches upto 99.99%. Ag–Cu–Ti alloy powder and (Ti+C) powder are mixed evenly by adopting a mechanical mixing method. They are turned into a paste by alcohol and placed between C_f/SiC composite and TC4 alloy. The brazing process was performed in vacuum at a pressure of 6×10^{-3} Pa, and within a range of 910–950 °C for 5–25 min holding time. All the specimens were furnace-cooled to room temperature.

Subsequent to brazing, the specimen was cut through cross-section and processed by standard metallographic technology for microstructure examination. The microstructures of the joints were examined by Aleo-1450 scanning electron microscopy (SEM) along with a KEVEX Sigma energy dispersive spectrometer (EDS). The C_f/SiC composite was removed completely and appropriately grounded before the joints were analyzed by X-ray diffraction (XRD) with Cu Kα radiation. The shear strength testing of the joint at room temperature, 500 °C and 800 °C was performed by means of a specially designed figure at a crosshead rate of 0.5 mm/min. The schematic is shown in Fig. 2. The shear strength of brazed joints was an average value of three measurements in this study.

3. Results and discussions

3.1. Microstructure of the brazed joint

Fig. 3 shows the backscattered electron images of the joint brazed at 910 °C for 5 min using Ag–Cu–Ti–(Ti+C) mixed powder with (Ti+C) 15 vol%. Results of chemical analysis by EDS on each phase are listed in Table 2.

As shown in Fig. 3(a), C_f/SiC composite was successfully joined to TC4 alloy with Ag–Cu–Ti–(Ti+C) mixed powder. The upside is C_f/SiC composite, and the underside is TC4 alloy. Between the C_f/SiC composite and TC4 alloy is interlayer, which is uniform and compact. It can be clearly observed that a compact reaction layer formed adjacent to C_f/SiC composite and several diffusion layers with different thicknesses were formed at TC4 alloy. The joint interfaces were well bonded and devoid of defects such as cracks and voids. The whole joint can be divided into three parts, and marked as I, II and III.

Part I shows the reaction layer adjacent to C_f/SiC composite, the magnified microstructure is displayed in Fig. 3b. It was expected that Ti element in the filler material would react with C_f/SiC composite, resulting in protrusion of C fiber and permeation of molten alloy into the voids and cracks of C_f/SiC composite. This appearance can increase the contact area between C_f/SiC composite and interlayer, which is beneficial to increase interfacial bonding strength. It is also obviously demonstrated that the reaction of Ti with SiC is more violent than that with carbon fiber. According to the analysis of the EDS, the reaction layer (marked by A) adjacent to the C_f/SiC composite is mainly composed of Ti, C, and Si elements; it is determined to be Ti_3SiC_2 according to the XRD analysis in Fig. 4a. There is a small amount of TiC wrapped to the carbon fiber from the reaction of Ti with the carbon fiber in the composite. There are some dark gray dots (marked as B) in the region C, which is rich in Cu and Ti elements. According to the analysis by the EDS and XRD, it can be concluded that the dark gray dots are Ti_5Si_3.

As shown in Table 2, during the brazing, the molten braze tends to be separated into two liquids, one is rich in Ag (white phase), the other is rich in Ti and Cu. Therefore, during the following cooling process, both of them get distributed in the interlayer and form the part II. In the interlayer, there are some