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Brazing of C/C composite and Ti-6Al-4V with graphene strengthened AgCuTi filler: Effects of graphene on wettability, microstructure and mechanical properties

Duo LIU [a,b], **Yanyu SONG** [b], **Yinghao ZHOU** [a], **Xiaoguo SONG** [a,*], **Wei FU** [a], **Jicai FENG** [a,b]

[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, Harbin Institute of Technology at Weihai, Weihai 264209, China*

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Abstract Graphene nanosheets (GNSs) strengthened AgCuTi composite filler ($AgCuTi_G$) was used to braze C/C composite and Ti-6Al-4V. The effects of GNSs on the wettability of $AgCuTi_G$ filler on the C/C composite surface and the interfacial microstructure and mechanical properties of brazed joints were investigated. The results indicate that the addition of GNSs reduced the wettability of $AgCuTi_G$. The interfacial microstructure of brazed joints evolved with the addition of GNSs, where Ti_3Cu_4 and $TiCu_4$ were converted to TiCu and the thickness of the reaction layer adjacent to the base material decreased. The maximum shear strength of joints brazed at 0.3 wt% GNSs was 23.3 MPa (880 °C/10 min). Further adding GNSs deteriorated the shear strength of the joints. Fracture of the joints occurred in the C/C composite substrate and the TiC layer adjacent to C/C composite.

1. Introduction

As a promising high-temperature structure material, carbon fiber reinforced carbon matrix composite (C/C composite) possesses low coefficient of thermal expansion (CTE), good anti-fatigue ability, high thermal conductivity and high-temperature mechanical properties, and is widely utilized in aeronautics and space industries.[1–3] To enhance their potential for practical applications in aerospace components, it is neces-

* Corresponding author.
E-mail address: songxg@hitwh.edu.cn (X. SONG).

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sary to join C/C composite to other materials. Ti-6Al-4V alloy (TC4) can be widely applied in aerospace industries owing to its excellent mechanical properties such as high specific strength and strong corrosion resistance.[4,5] As part of a proposed nozzle component, the bonding of C/C composite and TC4 can greatly decrease the weight and increase the efficiency of rocket engines.[6]

Among different kinds of joining methods, brazing is a common method to join C/C composite to metals because of its strong adaptability and low cost. However, the wettability of filler metals on composite surface was a problem in brazing C/C composite to metals.[7–11] Previous research primarily focused on the effects of active elements on the wettability of filler alloy. Singh et al. investigated the effect of Ti content in different filler systems on the wettability on C/C composite surface.[12] The wettability of Pd-35Co, Pd-40Ni, 63Ag-35.3Cu-1.75Ti and 68.8Ag-26.7Cu-4.5Ti fillers on C/C composite was reported by Asthana et al.[13] Several studies reported the wetting process of fillers on C/C composite. In addition, high residual stress occurred at the brazed joints due to the diversity in elasticity modulus and CTE between C/C composite and metals. Therefore, composite filler, which is prepared by adding reinforcement particles with a high elasticity modulus and a low CTE into traditional active fillers to improve the strength of brazed joints, has attracted great interest in recent years. Lin et al.[14] used TiB_2 reinforced Cu-Ni composite filler to join C/C composite to TiB_w/TC4, and the shear strength of brazed joints was improved. The use of micro-SiC particles decreased the thickness of reaction layers near C/C composite and reduced the mismatch of CTEs between C/C composite and TC4, which led to a reduction of the residual stress of the joints.[15] Zhou et al. analyzed the strengthening mechanism of nano-Al_2O_3 particles in improving the mechanical properties of brazed joints.[9] Graphene, as a perfect two-dimensional material of sp2-bonded carbon atoms, has attracted wide attention owing to its excellent comprehensive properties including high Young's modulus, fracture strength, thermal conductivity and specific surface area.[16,17] In addition, GNSs composed of a few graphene layers possess properties similar to those of single-layer graphene, and are more prone to produce and handle.[18] GNSs have been proposed for potential applications in the nanoelectronics field,[19] and applied to improve the mechanical properties of materials.[20]

Therefore, GNSs reinforced AgCuTi composite filler was selected to join C/C composite to TC4 alloy in this study. The wettability of AgCuTi filler with different GNSs contents on C/C composite was studied. The effects of the GNSs content on the interfacial microstructure and mechanical properties of brazed joints were investigated.

2. Experimental procedure

The substrate materials used in this study were C/C composite and TC4 alloy. C/C composite was cut into specimens with sizes of 20 mm × 20 mm × 5 mm and 5 mm × 5 mm × 5 mm for wetting and brazing experiments using a diamond cutting machine. TC4 alloy was cut into specimens with a size of 20 mm × 10 mm × 3 mm by a wire electric discharge machine. $AgCuTi_G$ filler was prepared by adding GNSs and titanium powder (4.5 wt%) into AgCu eutectic powder filler (Ag-26.7 wt%Cu). The contents of GNSs in the composite filler were 0 wt%, 0.1 wt%, 0.3 wt%, 0.5 wt% and 0.8 wt%, respectively. Then the mixture was milled for 4 hours with a speed of 150 r/min using a QM-SB planetary ball mill. The composite filler powder was pressed into a ∅6 mm × 4 mm cylinder under a pressure of 3 MPa. All the specimens were polished and ultrasonic cleaned in acetone for 10 min.

The wetting experiments were conducted through the sessile drop method, which were carried out in a high-temperature wetting measuring device under a vacuum of 5×10^{-4} Pa. The processed C/C composite substrate was placed on the sample stage and adjusted to a horizontal position. $AgCuTi_G$ was placed at the center of C/C composite. To ensure temperature consistency in the furnace, the sample assembly was firstly heated to 750 °C at a rate of 20 °C/min and held for 10 min. Then it was heated to 880 °C at a rate of 5 °C/min and held for a period of time. Finally, the assembly was cooled down to 400 °C at a rate of 5 °C/min and then furnace-cooled down to the room temperature. The brazing experiments were performed in a vacuum furnace under a vacuum of 3×10^{-3} Pa. $AgCuTi_G$ filler was placed between C/C composite and TC4. The process parameters were similar to those of the wetting experiments.

The polished cross-sections of wetting samples and C/C composite/TC4 brazed joints were examined with a field emission scanning electron microscope (SEM) equipped with an energy dispersive spectrometer (EDS) to observe the interfacial microstructure morphology. The phase compositions of the interface was identified by X-ray diffraction (XRD). The shear strength of the brazed joints was tested with an Instron 5967 universal material testing machine. A schematic diagram of the shear test is shown in Fig. 1. The specimens were loaded by the testing machine with a constant displacement rate of 0.5 mm/min. At least 4 specimens brazed at the same brazing parameters were tested to obtain an average shear strength. The fracture surface was observed using SEM and EDS.

3. Results and discussion

3.1. Effects of GNSs on the wettability of $AgCuTi_G$ filler

Fig. 2(a) shows the variation of the drop height with time for different GNSs contents during the isothermal holding at temperature T = 880 °C. It can be seen from the image that the content of GNSs had a great effect on the wettability of

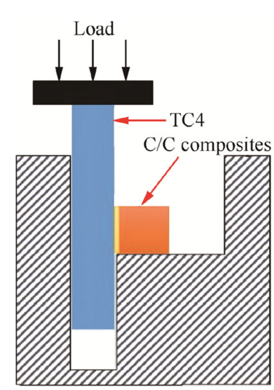

Fig. 1 Schematic diagram of shear test of C/C composite/$AgCuTi_G$/TC4 joints.

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