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Interfacial microstructure and mechanical properties of TiAl and C/SiC joint brazed with TiH_2–Ni–B brazing powder

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ABSTRACT

$(TiH_2\text{–}66Ni)_{1-x}B_x$ (x = 3 wt.%) brazing powder was fabricated by mechanical milling of a TiH_2, Ni and B mixture with the milling time ranged from 30 to 180 min. TiAl alloy and C/SiC composite were successfully brazed using this filler metal at 1180 °C for 10 min. The microstructure and mechanical properties of the brazed joints were investigated. The typical microstructure of the joint was divided into three characteristic zones, including the TiC reaction layer formed adjacent to C/SiC composite, the TiB-whisker reinforced central zone, and the β layer transformed from TiAl alloy. The in situ synthesized TiB whiskers acted as an effective reinforcement phase aid to decrease the residual stress and improve the shear strength of the joints. The joint strength reached 105 MPa at room temperature, and cracks primarily propagated in the C/SiC substrate with the pull-out of carbon fibers and partially in the TiC layer and τ_3 phase. The joint strength decreased slightly with the testing temperature increased to 500 °C, and remained at 70 MPa when tested at 600 °C. The crack propagation path diverted from the TiC reaction layer to the τ_3 phase when the joint was tested at 600 °C.

1. Introduction

Owing to the embedded carbon fibers, a carbon fiber reinforced silicon carbide (C/SiC) composite possesses higher fracture toughness than SiC ceramic and other merits such as low density, excellent oxidation and high-temperature strength [1]. It is a promising thermal-structural material for applications in the hypersonic aircraft thermal structure, advanced rocket propulsion thrust chambers, cooled panels for nozzle ramps and brake disks. Recent studies have shown that the three-dimensional C/SiC composite is an ideal material both for nozzles of solid rocket motors and for extendible nozzles of upper stage engines [2]. However, the assembly of a nozzle component requires joining a C/SiC composite nozzle to a metallic holder. TiAl alloys are potential materials for nozzle holders because of their low density and high specific strength at elevated temperatures [3]. Thus, reliable joining of C/SiC composite to TiAl alloy is essential for elevating the operating temperature and saving the weight of the component.

Numerous methods of ceramic–metal joining, including diffusion bonding, reaction forming and various types of brazing, have been extensively investigated. Among the methods available, active metal brazing is a simple and cost-effective technique to join composites [4–11]. When Ag–Cu–Ti brazing alloy was applied to braze TC4 and C/SiC composite, the joint strength was improved with the addition of optimum W or carbon fiber content in the brazing alloy [4–7]. However, the service temperature of such joints was restricted to 500 °C, which was not

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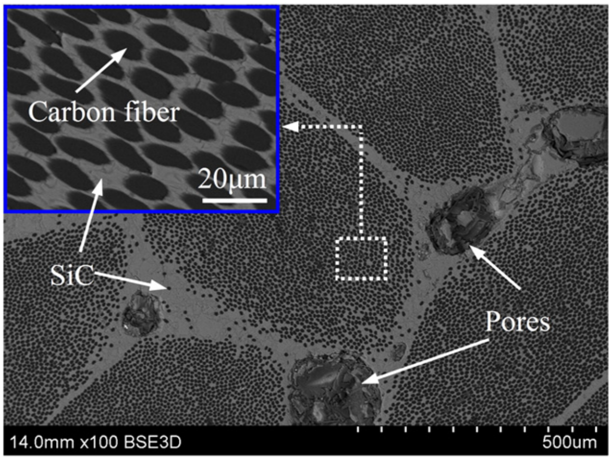

Fig. 1 – Microstructure of the C/SiC composite.

sufficient for specialized aerospace applications [12]. Ti and C/SiC joints obtained from Ni-based metallic glass alloys displayed intimate interfacial bonding though cracks might be observed in the C/SiC substrate [8]. Ti–Cu composite foils were used to join C/SiC composite and niobium alloy, with the shear strength of the joint reaching 34.1 MPa. But, the joint strength at high temperature was not reported [11]. As a consequence, the development of high-temperature brazing technologies is a major challenge in joining C/SiC to metal.

Compared with Ag- or Cu-based brazing alloys, joints obtained from Ti-based brazing alloys presented better high-temperature mechanical properties [13–15]. More recently, TiH_2–Ni filler metal has been demonstrated to have the capability of producing high strength joints suitable for elevated temperature applications [16,17]. Therefore, the filler metal based on the TiH_2–Ni system was selected to join TiAl and C/SiC in this work. In addition, large residual stress can be yielded in the joint due to the high thermal expansion coefficient (CTE) mismatches between TiAl and C/SiC composite [18,19]. To mitigate the residual stress, B powders were added into the TiH_2–Ni brazing powder. The in-situ synthesized TiB whiskers with a suitable content were beneficial to reduce the residual stress and reinforce the joint, as demonstrated in our previous work [20]. Moreover, the application of brazing powder is more favorable than brazing foils to join a ceramic–metal component with a complex shape. The method of mechanical milling was used to fabricate the homogeneous and refined brazing powder.

In this study, $(TiH_2–66Ni)_{1-x}B_x$ (x = 3 wt.%) filler metal was fabricated by mechanical milling of a TiH_2, Ni and B mixture. Effect of milling time on the microstructure of the brazing powder was analyzed. TiAl alloy and C/SiC composite were brazed using this filler metal at 1180 °C for 10 min. The correlation between joint microstructure and shear strength both at room temperature and elevated temperatures was investigated.

2. Experimental Procedures

Fig. 1 shows the microstructure of the three-dimensional C/SiC composite fabricated via the polymer infiltration and pyrolysis (PIP) process. The density of the composite is 1.86 g/cm^3 and its porosity is 11.7 vol.% measured by Archimedes' method. The carbon fibers are distributed in the composite in the form of bundles and each bundle consists of 12×10^3 pieces of carbon fibers. The volume fraction of carbon fiber is 45% in C/SiC composite. TiAl alloy with a nominal composition of Ti–43Al–9V–0.3Y (at.%) was fabricated by the vacuum induction skull melting (ISM) technique. The microstructure of the TiAl substrate displayed a lamellar characteristic, which mainly consisted of γ and β (or B_2) phases. The sizes of C/SiC composite and TiAl alloy for brazing were 5 mm × 5 mm × 5 mm and 30 mm × 10 mm × 2 mm, respectively. Surfaces of the TiAl sample to be brazed were grounded with 800 grit SiC paper and then all specimens were ultrasonically cleaned in acetone for 10 min before vacuum brazing.

Due to its high activity, Ti powder was easily oxidized or reacted with Ni during mechanical milling. Thus, TiH_2 powder was applied as a good substitute in the mixture, as suggested by Ref. [15,17]. The decomposition of the TiH_2 phase occurred

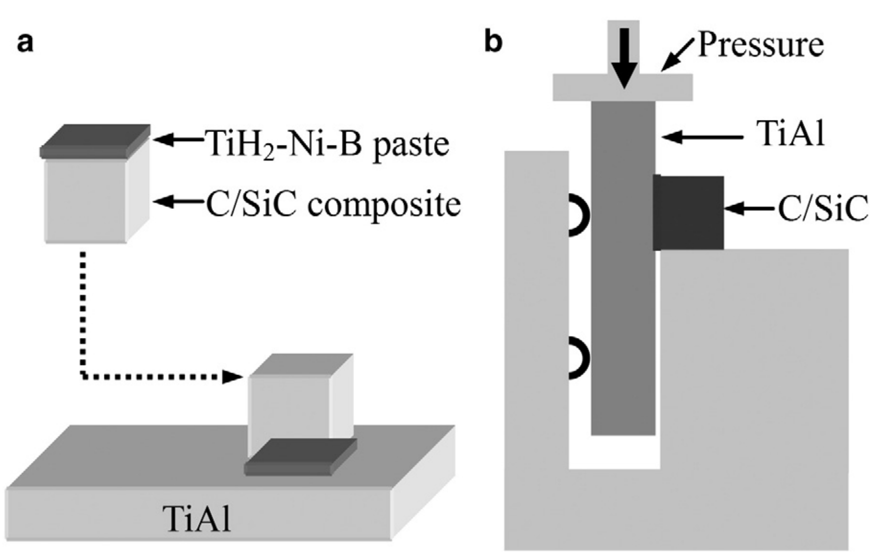

Fig. 2 – Schematic diagram of (a) the assembly structure and (b) shear test.