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Interfacial reactions and zigzag groove strengthening of C/C composite and Rene N5 single crystal brazed joint

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Abstract

C/C composites are brazed in vacuum to the Rene N5 single crystal superalloy using the AgCuTi filler metal with the flat and zigzag triangular groove interfaces. The structure of the C/C/TiC/Ag(s.s)+Cu(s.s)+Ti(Cu,Ni)/Ti(Cu,Ni)$_2$+Ti(Cu,Ni)$_3$+Ti(Cu,Ni)$_2$/Ni(s.s)/(Cu,Ni)+Ag(s.s)/Rene N5 is formed at the joint interface. The shear strength of the joint with the zigzag triangular groove interface is improved greatly compared to that of the joint with a flat interface. The improvement stems from the reduced residual stress, extended joint area, and enhanced pinning effect.

Keywords: C/C composites; Rene N5; Brazing; Microstructure; Mechanical property

1. Introduction

Owing to attractive properties such as the low density, small coefficient of thermal expansion (CTE), ablation resistance, outstanding high-temperature mechanical strength, and excellent oxidation resistance, carbon/carbon (C/C) composites are considered good high-temperature structural materials for high thrust–weight ratio turbine engines, gas turbines for power plants, heat shields for space vehicles, and solid rocket motor nozzles [1–3]. Rene N5 is a typical second-generation single crystal that is widely used in turbine blades, vane materials in aircraft engines, as well as land-based gas turbines on account of its excellent mechanical strength as well as resistance to creep, corrosion, and oxidation at high temperature. However, being intrinsically brittle and difficult-to-machine, it is difficult to manufacture C/C composites into components with a complex shape thus hampering wider applications. Consequently, most applications in the aerospace and nuclear industry require joining C/C to metals, ceramics, or composites, and proper joining of C/C and Rene N5 has industrial potential.

As ceramic materials, it is difficult to join C/C by traditional fuse welding due to the high melting point. Although active metal brazing is a simple and cost-effective technique to join ceramics and C/C has been joined to Ti [4], TiAl [5], Cu [6–8], and Ni [9–11] based alloys by active vacuum brazing. However, joining of C/C with the nickel-based single crystal super alloy has seldom been reported. The coefficients of thermal expansion (CTE) of the C/C composite are about $\sim$0–1.0 $\times$ 10^{-6} K^{-1} in the temperature range between 20 °C and 250 °C and $\sim$2.0–4.0 $\times$ 10^{-6} K^{-1} from 250 to 2500 °C [12]. In comparison, the CTE of Rene N5 of about 12–16 $\times$ 10^{-6} K^{-1} is much larger than that of C/C and the mismatch in the CTEs between C/C and Rene N5 results in large thermal stress at the joining interface during the brazing process. In this respect, several measures such as drilling [5], wave interface [13], and stress relief interlayer [9,10] have been taken to accommodate the thermal stress.

In this work, C/C and Rene N5 are brazed with the active Ag–Cu–Ti filler in vacuum. The microstructure of the brazed joint is examined and the metallurgical process of the brazed joint is analyzed. In addition, a series of the zigzag triangular

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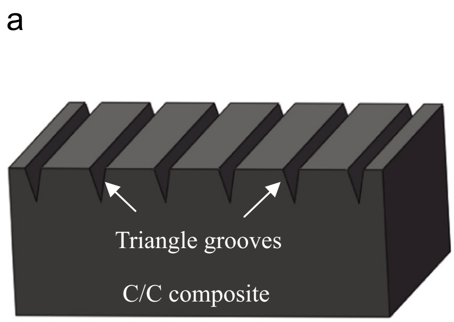

Fig. 1. (a) Schematic showing the structure of zigzag triangle grooves on C/C. (b) Assembly sketch of the C/C and Rene N5 brazed joint.

groove structure is prepared by applying a laser to the C/C joining surface and its influence is also evaluated and discussed.

2. Materials and experimental procedures

2.1. Materials

The C/C composites obtained from Boyun New Materials Co., Ltd. are semi-three-dimensional C/C composites fabricated by needle felts and carbon fiber cloths. The nominal composition of Rene N5 is Ni–7 wt%/Cr–7.5 wt%/Co–6.5 wt%/Ta–6.2 wt%/Al–5 wt%/W–3 wt%/Re–1.5 wt%/Mo and that of the fillers (0.1 mm thick foil or paste) is Ag–27 Cu–3 Ti (wt%). The C/C composite and Rene N5 were made into 4 mm × 5 mm × 5 mm rectangular blocks for metallographic analysis and shear strength tests.

To balance the mismatch of CTEs between C/C and Rene N5 and improve the property of the brazed joint, a series of parallel zigzag triangle grooves were micro-machined on the C/C joining surface by a laser beam. The distance between adjacent grooves was about 1 mm and the groove depth varied between 450 μm and 600 μm as shown in Fig. 1a.

2.2. Brazing procedure

Prior to brazing, the joining surfaces of the C/C and Rene N5 were polished by 400, 600, and 1000 grit silicon carbide paper and then cleaned ultrasonically in ethanol for 15 min.

The AgCuTi paste was prepared with ethanol, filled, and covered the grooves with the paste. For the C/C composite blocks with zigzag triangular grooves, the samples with the filler metals in the grooves were put in a vacuum furnace and heated to 850 °C for 3 min to melt the filler metal and cover the grooves. For comparison, a C/C sample with a flat joining surface was also prepared.

The AgCuTi foil was sandwiched between the C/C (flat or zigzag interfaces) and Rene N5 substance and a normal load of 1 kPa was applied to the assembly. The assembly of Rene N5 and C/C with zigzag triangular grooves is shown in Fig. 1b. The brazing experiments were carried out at 910 °C for 10 min in a vacuum furnace evacuated to 3×10^{-3} Pa. The temperature–time curve of the brazing process is shown in Fig. 2.

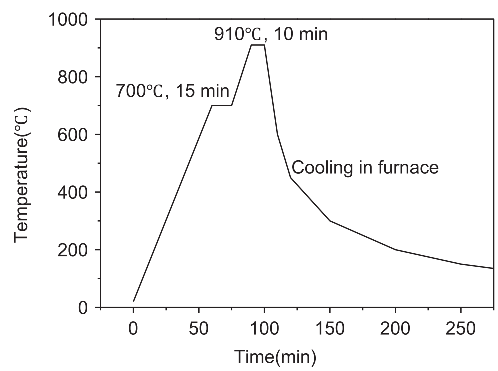

Fig. 2. Temperature–time curve of the brazing process.

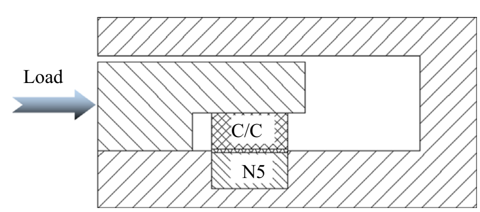

Fig. 3. Schematic illustrating the shear strength test of the joint samples.

2.3. Microstructure and joining strength characterization

The microstructure and fracture morphology of the brazed joint were characterized by CS3400 scanning electron microscopy (SEM) and energy-dispersive X-ray spectrometry (EDS). The phase constituents cross the brazed joints were evaluated by X-ray diffraction (XRD, D/Max2500) on the fracture surface (C/C side) and around the middle zone of the brazed joint by polishing the Rene N5 fracture side layer-by-layer. The shear strength of the joints was determined on the Gleeble-1500 thermomechanical simulator machine at a constant speed of 0.5 mm/min and the schematic of the shear strength test is presented in Fig. 3.

3. Results and discussion

The cross-sectional microstructures of the C/C/AgCuTi/Rene N5 joint with a flat interface (noted as flat joint) are shown in Fig. 4. The flat joint exhibits sound bonding at the