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Effect of Ti−Al content on microstructure and mechanical properties of C_f/Al and TiAl joint by laser ignited self-propagating high-temperature synthesis

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Abstract: C_f/Al composites and TiAl alloys were joined by laser ignited self-propagating high-temperature synthesis (SHS) with Ni−Al−Ti interlayer. The effect of Ti−Al content on interfacial microstructure and mechanical properties of the joints was investigated. Localized melt of the substrates occurred in the joints. γ-$Ni_{0.35}Al_{0.30}Ti_{0.35}$, $NiAl_3$ and Ni_2Al_3 reaction layers formed adjacent to the substrates. Joint flaws, such as pores and cracks, made the joint density decrease and worked as the fracture source, which led to the sharp decline of joint strength. Additive Ti−Al increased joint density and strengthened the interlayer adhesion to C_f/Al. The joint flaws could be controlled by changing the Ti−Al content. When the Ti−Al content was 0.1, the joint was free of cracks with high density and reached the maximum shear strength of 24.12 MPa.

Key words: C_f/Al composite; TiAl alloys; joint; self-propagating high-temperature synthesis; interlayer; Ti−Al content

1 Introduction

As a new kind of structural materials, carbon fiber-reinforced aluminum matrix composites (C_f/Al) have low density and thermal expansivity, high specific strength and stiffness, excellent electrical and thermal conductivities, which make them successfully demonstrate their potential in aerospace and automotive applications [1−3]. Titanium aluminide (TiAl) is also characterized by its low density and high specific strength at elevated temperature [4−6]. The joining of C_f/Al composites and TiAl alloys allows us to take full advantage of their merits and further expand the scope of their applications.

However, owing to their notable differences in properties, especially for the temperature sensitivity and low melting point of C_f/Al composites compared with TiAl alloys, sound joint of C_f/Al composites and TiAl alloys cannot be obtained easily. High temperature, usually over 1073 K [7,8], was employed in the brazing of TiAl alloys, which was obviously inappropriate for the aluminum matrix composites. Other conventional welding processes, such as diffusion welding [9] and fusion welding [10], would also damage the connection between the reinforced fibers and matrix in composites and cause the formation of brittle Al_4C_3 in the joint. Thus, innovative welding method must be developed.

Self-propagating high-temperature synthesis (SHS) is a promising technique, and can be used to join dissimilar materials [11−13]. In the joining process, exothermic reaction occurs and compounds are in-situ synthesized. Then, materials are joined by the localized heat without thermal damage. Successes have been achieved in the joining of TiAl alloys and ceramics with Ti−Al−C by FENG et al [4,11] and WANG et al [14] and Ni−Al interlayer by PASCAL et al [13]. The ignition temperature of joining interlayer, such as Ti−Al−C and Ni−Al is close to the melting point of aluminum. So far, the SHS joining has not applied on the aluminum composites. And one important reason is that traditional ignition method, such as thermal explosion and arc ignition, cannot efficiently protect the low-melting aluminum composites when ignite the interlayer.

In this work, SHS joining was applied on the C_f/Al composites and TiAl alloys with Ni−Al−Ti interlayer. Laser beam was employed to ignite the interlayer for its small heating area and high heating rate. The typical interfacial microstructure of SHS joint was characterized. In addition, the effect of Ti−Al content on the joint microstructure and shear strength was systematically evaluated.

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2 Experimental

The C_f/Al composites applied in this work had a fiber volume fraction of 50% and metal matrix of 6061 aluminum alloy. The C_f/Al composites were achieved through extrusion casting method, with a density of 2.189 g/cm^3. TiAl alloys had the nominal composition Ti−48Al−7V−0.3Y (mole fraction, %). The C_f/Al and TiAl substrates were cut into 5 mm × 5 mm × 4 mm and 12 mm × 8 mm × 2 mm pieces, respectively. All the joined surfaces were polished by SiC papers up to grit 1000, and all the samples were cleaned ultrasonically in acetone for 15 min prior to the joining.

Powder mixtures of titanium (45 μm, 99.5%), aluminum (45 μm, 99.5%), and nickel (63 μm, 99.5%) were used and weighed out according to corresponding composition. The weighed powders were dry-mixed thoroughly in the tumbler ball mill using Al_2O_3 balls for 2 h, with the rotation speed of 300 r/min. The ball-to-powder mass ratio was 10:1. Then, the milled powders were cold pressed under the pressure of 200 MPa into disc specimens of 10 mm in diameter and 1 mm in thickness.

The joining process proceeded in the atmospheric environment. The green powder compact was sandwiched between the C_f/Al and TiAl substrates with a pressure of 2 MPa provided by special fixture. A laser beam of output power of 100 W and beam size of 0.2 mm heated the interlayer for 5 s and ignited the interlayer. Figure 1 shows the schematic diagram of the joining system.

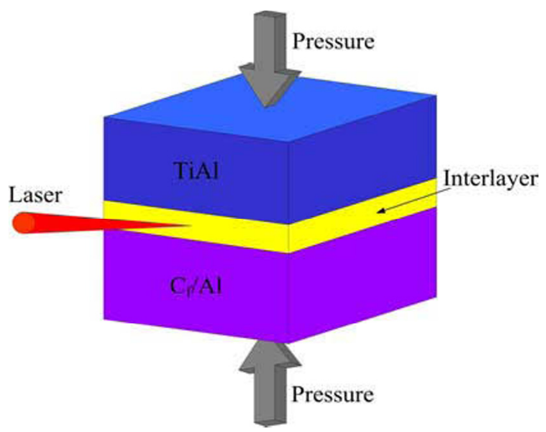

Fig. 1 Schematic diagram of joining system

After joining process, the polished cross-sections of the joints and reaction products were examined to characterize the microstructures by scanning electron microscopy (SEM) coupled with energy dispersive spectroscopy (EDS). The metallographic phases were identified by X-ray diffraction (XRD) (JDX-3530 M) with Cu K_α radiation operated at a voltage of 40 kV, working current of 40 mA and angle incidence of 10−90°. As shown in Fig. 2, room temperature shear test was conducted employing an Instron-1186 universal testing machine by a specially designed fixture at a crosshead rate of 0.5 mm/min and the average strength of three joints joined under the same conditions was used.

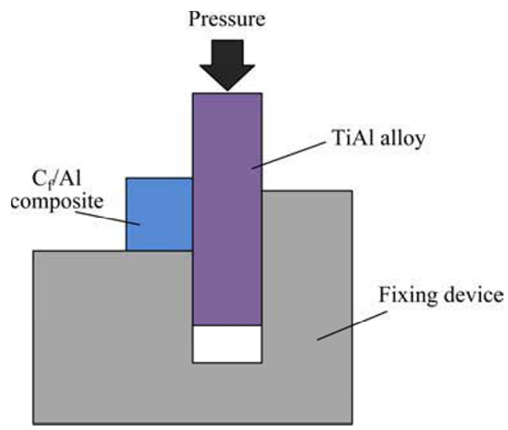

Fig. 2 Schematic diagram of shear test of joint

3 Results and discussion

3.1 Selection of interlayer

In SHS joining, the interlayer served as heat source and filler metal. Thus, it determined the joining quality that whether the interlayer had high exothermicity and the reaction products were homogeneous with the substrates in physical and chemical properties. Owing to the particular heat transfer condition, few reactant powders for fabricating materials can meet the requirement. The Ti−Al−C interlayer was regarded as the first choice in SHS joining. According to previous studies [11,15], the ignition temperature of Ti−Al−C interlayer was close to the melting point of aluminum. Its exothermic reaction consisted of two stages. The first stage is that Ti reacts with Al and a small quantity of heat is released, then the reaction of Ti and C is induced by the first stage and large quantity of heat is released. In this work, aluminum composites limited the integral heating of thermal explosion. When the Ti−Al−C interlayer was ignited in other ways, the reaction of Ti and C in the second stage cannot be induced owing to the cooling effect of adjacent substrates. Only a certain amount of heat was produced, which would lead to the weak bonding. Clearly, interlayer with high and rapid exothermicity was needed.

According to the Ni−Al phase diagram, compounds, such as $NiAl_3$, Ni_2Al_3, NiAl, can be formed between Ni and Al. The addition of Ni allowed the formation of reaction layers between the interlayer and substrates, which were the key to interfacial bond formation. When the powder mixture of Ni and Al was employed, enough