Materials and Design 110 (2016) 130–137

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Joining of C_f/Al composites and TiAl intermetallics by laser-induced self-propagating high-temperature synthesis using the Ni-Al-Zr interlayer

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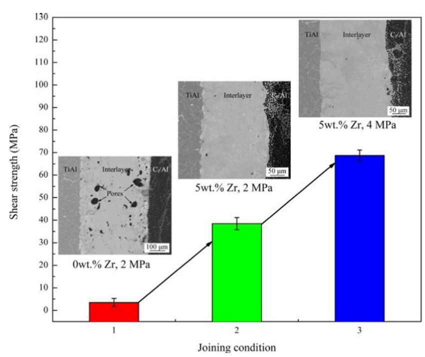
HIGHLIGHTS

- C_f/Al composites and TiAl intermetallics are successfully joined by a novel laser-induced self-propagating high-temperature synthesis joining method.
- The adiabatic temperature of the Ni-Al-Zr interlayer is calculated.
- Eutectic composites of NiAl + Ni_2AlZr + $Ni_3Al_5Zr_2$ are in-situ synthesized in the joining process.
- A nanoscale thin Zr-C layer forms on the $NiAl_3/C_f$ interface and greatly enhances the joining quality.
- The maximum joint shear strength is 68.71 MPa with 5 wt.% Zr at 4 MPa.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 16 June 2016
Received in revised form 26 July 2016
Accepted 27 July 2016
Available online 29 July 2016

Keywords:
Metal-matrix composites (MMCs)
Intermetallics
Microstructure
Mechanical property
Self-propagating high-temperature synthesis
Welding/joining

ABSTRACT

To extend the materials application and achieve composite structures with combined advantages, the C_f/Al composites were joined with TiAl intermetallics by a novel laser-induced self-propagating high-temperature synthesis joining method. In this study, a Ni-Al-Zr interlayer was designed based on the calculation of the adiabatic temperature. The joint microstructure was characterized using scanning electron microscopy (SEM), energy dispersive spectrometry (EDS), transmission electron microscope (TEM) and X-ray diffraction (XRD). The results showed that the NiAl + Ni_2AlZr + $Ni_3Al_5Zr_2$ eutectic were produced during the joining. The Al_3NiTi_2, Ni_2Al_3 and $NiAl_3$ reaction layers formed respectively on both sides. A nanoscale thin Zr-C reaction layer formed on the $NiAl_3/C_f$ interface and greatly enhanced the bonding quality on the C_f/Al side. The effect of the interlayer composition and joining pressure on the joint microstructure and mechanical property was investigated. The highest joint shear strength was 68.71 MPa at a pressure of 4 MPa when the Zr content was 5 wt.%.

1. Introduction

Carbon fiber reinforced aluminum matrix composites (C_f/Al) possess the attractive properties, such as (i) low density, (ii) high specific strength and stiffness, (iii) excellent electrical and thermal conductibility, especially (iv) the good dimensional stability in moist and radiation environment [1–4]. TiAl intermetallics have also been attracting particular attention due to the high creep and oxidation resistance at elevated temperature [5–7]. Their successful joining can produce composite structures and achieve combined advantages of the merged structures. Unfortunately, such joining is a great challenge due to the inevitably large differences in the properties of the C_f/Al composites and TiAl intermetallics. Research on the C_f/Al composites shows

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http://dx.doi.org/10.1016/j.matdes.2016.07.128

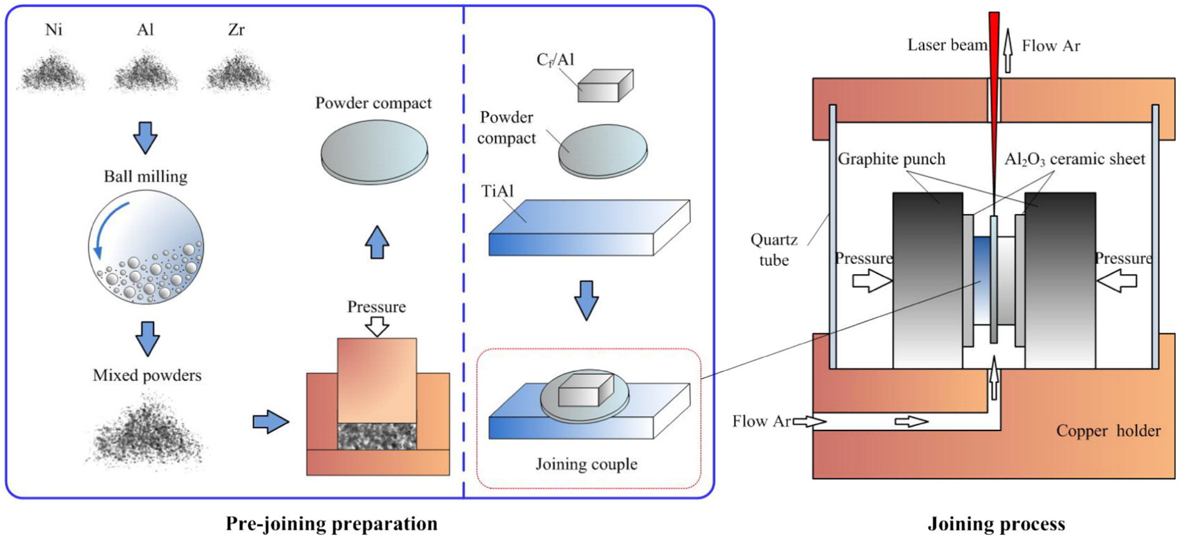

Fig. 1. Schematic diagram of the joining system.

that large pressure and long heat treatment above 823 K would cause the microcrack initiation and the excess interfacial chemical reaction between the carbon fibers and the aluminum matrix, thus leading to the degradation of materials properties [8–11]. Obviously, conventional joining methods, such as diffusion bonding and fusion welding, cannot meet the requirements. Similarly, brazing is also not a good solution due to the lack of appropriate filler metal. Researchers tried to braze the C_f/Al [12] and the TiAl [13] using the aluminum-base filler metals. However, sound joints could hardly be obtained because of the severe interfacial reaction and brittle reaction products. So far, few satisfied joining of C_f/Al composites and TiAl intermetallics has been reported. Therefore, it is essential to develop novel joining techniques.

Self-propagating high-temperature synthesis (SHS) is a promising technology, and can be used to synthesize composites and join dissimilar materials [14]. During the joining, the exothermic reaction occurs in the interlayer and acts as a local high-temperature source, reducing the welding heat input and minimizing the possible thermal damage of the substrates [15]. Meanwhile, a gradient layer can be in situ synthesized during the joining and relieve the materials property difference. Great efforts have been made on this topic. Pascal et al. [16] synthesized NiAl by SHS from an equimolar mixture of Ni and Al powders and simultaneously joined to a superalloy substrate. Recently, microwave assisted SHS joining of SiC ceramics was performed by Rosa et al. [17] exploiting the Ti-Si-C interlayer. In our previous study [18,19], TiAl intermetallics were successfully joined with themselves using the Ti-Al-C interlayer and with the TiB_2/Ni cermet using the Ti-Al-C-Ni interlayer. Although some achievements have been made, these reported researches mainly focus on the high-temperature materials, such as the superalloys, ceramic and intermetallics. The SHS joining of the aluminum matrix composites has seldom been discussed.

In this study, the C_f/Al composites are successfully joined with the TiAl intermetallics by the SHS using a Ni-Al-Zr interlayer. To minimize the possible thermal effect on the substrates during the ignition process, the laser beam is employed here (featuring small heating zone and high heating rate). The adiabatic temperature of the interlayer is calculated. The typical joint microstructure is examined. In addition, the effect of the interlayer composition and joining pressure on the interfacial microstructure and joint mechanical property is systematically investigated.

2. Experimental procedure

The C_f/Al composites used in this study had a fiber volume fraction of 50% and the 6061 aluminum matrix. TiAl intermetallics had the nominal composition of Ti-48Al-7V-0.3Y (at.%). Before joining, the C_f/Al and TiAl substrates were cut into pieces with the size of 5 mm × 5 mm × 3 mm and 12 mm × 8 mm × 2 mm, respectively. Then, the joining surfaces were polished by SiC papers up to grit 1000, and then cleaned ultrasonically in acetone for 15 min to eliminate impurities.

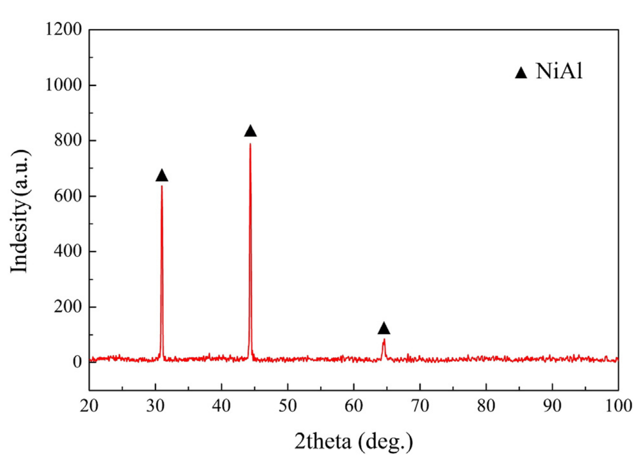

Fig. 2. XRD pattern of the as-synthesized Ni-Al reaction products.

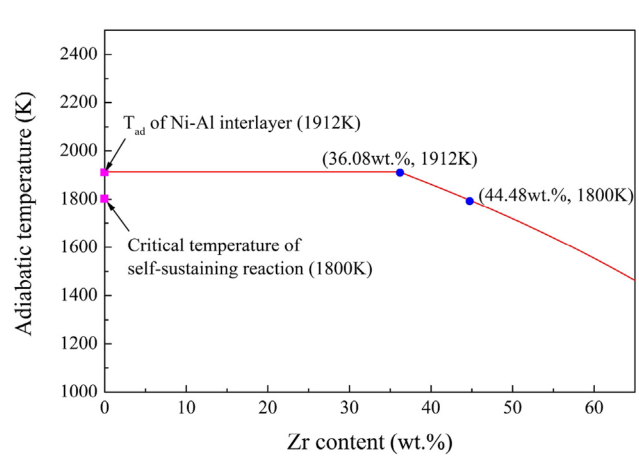

Fig. 3. Effect of Zr content on the T_{ad} of the Ni-Al-Zr system.