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Dissimilar joining of TiAl alloy and Ni-based superalloy by laser welding technology using V/Cu composite interlayer

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HIGHLIGHTS

- TiAl alloy and Ni-based superalloy was successfully welded by laser using V/Cu composite interlayer.
- Hard Al-Ti-Ni and Ti-Ni intermetallics replaced by soft V solid solution, Cu solid solution and Al-Cu-Ti intermetallics.
- High-temperature and room-temperature tensile properties have been studied.
- Joint properties have great increase by using V/Cu composite interlayer.

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ABSTRACT

Joining TiAl alloy to Ni-based superalloy is of great interest for applications in aerospace and automobile field. In present study, we report the feasibility of TiAl alloy to Ni-based superalloy welding through V/Cu composite interlayer carried out by laser. Detailed microstructural characterization, mechanical properties and fractured behavior of the joints were performed. The V/Cu composite interlayer remarkably decreased the formation of brittle phases and eliminated subsequent cracking compared with no interlayer and eventually improvement of mechanical properties of the joints. The tensile strength of room temperature and high temperature (873 K) were 230 MPa (reaching about 60% of the TiAl base metal) and 145 MPa, respectively. The study results indicate that insertion of V/Cu composite interlayer is very useful for laser welding of TiAl/Ni-based superalloy.

1. Introduction

TiAl alloys are regarded as ideal materials for high temperature application in the automobile and aerospace due to their low density, excellent high-temperature strength and modulus, as well as good high-temperature creep and oxidation resistance [1–4]. Ni-based superalloys are considered to be very important and widely used alloy in aero engine and gas turbines [5,6]. Therefore, the joining of TiAl alloy and Ni-based superalloy would be desirable material combination for reducing the structure weight and making full use of the high temperature performance advantages of the two metals. However, large differences in physical and chemical properties between the two metals make the dissimilar welding complex and difficult. Therefore, joining TiAl alloy to Ni-based superalloy is still a great challenge in engineering technology, and the joining technology has also been greatly restricted. So far, few literatures have been reported on joining TiAl to Ni-based alloy, and only brazing [7–9] and diffusion bonding [10–15] have been mentioned, and some useful insights and data have been obtained. These welding methods, however, are not flexible enough, and are usually limited to the factors such as joint type, workpiece size and shape, etc. In addition, from an engineering point of view, fusion welding is more attractive due to its more wide applications and better flexibility. But till now, little work has been reported about fusion welding of the two metals [16]. Due to the great differences of the two metals, the conventional fusion welding methods were considered unfeasible; nevertheless, laser welding has achieved successful joining where conventional joining techniques have failed [17–20]. Moreover, the rapid heating and cooling, low distortion, high accuracy and

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flexibility of this process are desirable for joining the dissimilar materials. In spite of these, direct laser welding of TiAl alloy and Ni-based superalloy is also confronted with the formation of brittle intermetallic compounds which would deteriorate the joint properties and even lead to joint cracking during the welding process. As with diffusion bonding, adding a suitable interlayer is also an important link for the successful joining by laser.

In this investigation, the V/Cu was selected as the composite interlayer. The chemical composition, microstructures and mechanical properties of laser-welded joints with V/Cu composite interlayer have been investigated and discussed. Its objective was to evaluate the weldability of TiAl alloy to Ni-based alloy and to provide some foundation for improving the mechanical properties of the dissimilar joints.

2. Experimental procedure

2.1. Materials and sample preparation

TiAl alloy with the composition of Ti-48Al-2Cr-2Nb (at.%) and Ni-based superalloy with the composition of Ni-22Cr-(C ≤ 0.56, Al ≤ 0.3, 0.30Ti, Fe ≤ 1.0, Mn ≤ 0.7, Si ≤ 1.5, P ≤ 0.054, S ≤ 0.035) (at.%) were used as base metals in this investigation. Test specimens with the dimension of 40 mm (length) × 20 mm (width) × 1 mm (thickness) were cut down from plates of both base metals by electro-discharge machine. Both pure V and Cu foils with 0.2 mm thick and 99.95% purity were used as interlayer, and the dimension of the two foils were 45 mm (length) × 1.1 mm (width). Before welding, the base metals and the filler metal were grinded to remove oxides, and then ultrasonically cleaned in an acetone bath and dried in air.

2.2. Design of the composite interlayer

It is known that Ti is a very active element, and easy to react with most other elements to form intermetallic compounds, except for a few elements such as Mo, Nb, Ta, V, W, Y, etc. Ni is also a reactive element that can form intermetallic compounds with many elements except for Ag, Cu, Cr, Rh, Re, etc. It indicates that no single element can neither form intermetallic compounds with Ti nor with Ni simultaneously. Thus, at least two layers of different elements would be needed for interlayer design, as shown in Fig. 1. A is an element that does not form intermetallic compounds with Ti, and B is an element that does not form intermetallic compounds with Ni. According to the binary alloy phase diagrams [21], the combinations of A and B should be Mo-Ag, Nb-Ag, Ta-Ag, V-Ag, W-Ag, Mo-Cu, Nb-Cu, Ta-Cu, V-Cu, W-Cu, Mo-Cr, V-Cr, W-Cr and Y-Cr, which do not form intermetallic compounds.

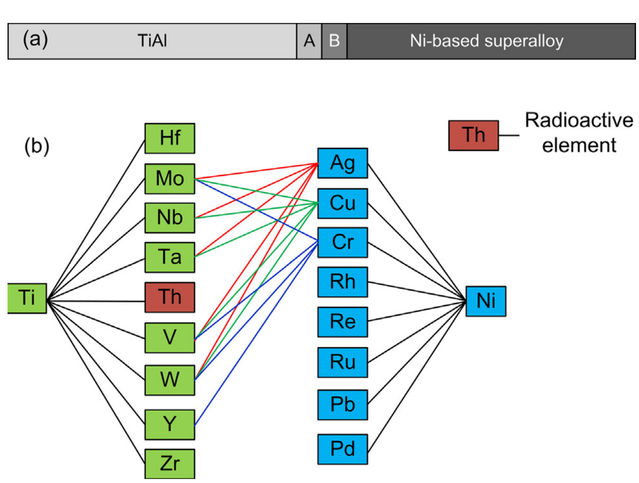

Fig. 1. Schematic diagram of composite interlayer design (a) and the metallurgical compatibility of Ti, Ni and other elements (b).

However, how to choose the best combination needs to be considered from the following two aspects [22]: (1) the smaller the difference of the melting point of the A and B is beneficial to welding; (2) the closer the difference of the coefficient of linear expansion between A and TiAl base metal, and B and Ni-based superalloy is favorable for welding. Based on (1), the combinations that can be selected are V-Cr (45 K), Y-Cr (361 K), Mo-Cr (760 K) and V-Cu (817 K), in turn. As can be seen, many combinations contain Cr, but the pure Cr is very brittle and hard, so it is very difficult to be made into thin sheet as interlayer. Moreover, the difference of the coefficient of linear expansion between Cr (6.2×10^{-6}/K) and Ni-based superalloy (17.5×10^{-6}/K (20–800 °C)) is large, which would lead to difficulties in welding.

In comparison with V-Cu, the linear expansion coefficient of V (8.3×10^{-6}/K) is close to TiAl alloy (11.0×10^{-6}/K (20–800 °C)), and the linear expansion coefficient of Cu (16.8×10^{-6}/K) is close to Ni-based superalloy (17.5×10^{-6}/K (20–800 °C)), which means that this combination is more suitable for welding of TiAl alloy and Ni-based superalloy.

2.3. Laser welding

The V/Cu composite interlayer was kept in contact between TiAl alloy and Ni-based superalloy in a self-constructed fixture. Single pass welding was used to melt the composite interlayer and a small part of the base metals and make them weld by a Nd:YAG pulse laser welding system (Type HKW-1050) with the wavelength of 1.064 µm. The schematic diagram of the welding process was shown in Fig. 2. The pulse current of 85A/95A, pulse duration 10 ms, pulse frequency 6 Hz, laser beam diameter 0.1 mm and welding speed of 180 mm/min were selected for welding the dissimilar materials without and with V/Cu composite interlayer. The laser parameters for the welding were determined according to the previous experimental results [24,25], and some corresponding adjustments were made on the basis. Due to the high melting point of the vanadium and the high laser reflection of Cu, the pulse current was increased. In order to decreasing the porosity defect, the welding speed was reduced in this experiment. The pure argon gas was blown on the front and back of the welding zone specimens during welding in order to prevent N_2, O_2 and H_2 from penetrating into the weld and reducing the joint properties. The argon shielding gas flowing was 20 L/min.

2.4. Microstructural analysis

After laser welding, the joint samples were cut using an electrical discharge cutting machine for microstructural examination and tensile tests. The samples for microstructural examination were prepared by applying standard metallographic procedures. The microstructure and fracture surfaces of the dissimilar joint were investigated using scanning electron microscopy (SEM, VEGA3) and chemical composition was

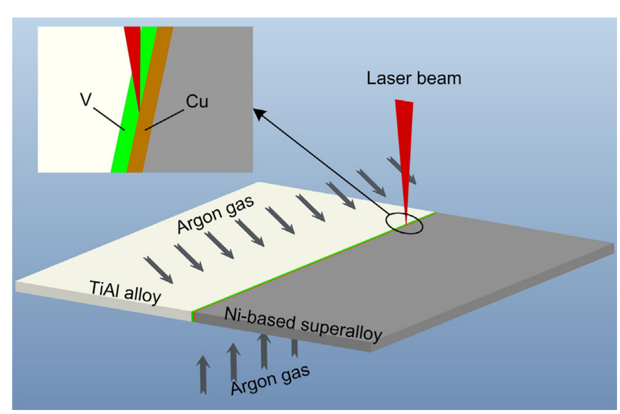

Fig. 2. Schematic diagram of the welding process.

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