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Diffusion bonding of gamma-TiAl using modified Ti/Al nanolayers

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ABSTRACT

Solid state diffusion bonding has been successfully employed to join γ-TiAl alloys. Processed in vacuum, at high temperature and pressure, the thin interfaces and the lack of structural discontinuity across the interface are the main advantage of this joining technique. An interlayer made of alternated Ti and Al nanometric layers that increases the diffusivity at the joint interface, was used in order to assist the bonding process of γ-TiAl alloys. The use of Ti/Al interlayer has efficiently reduced the joining temperature. Sound joints have been achieved at a temperature of 900 °C under a pressure of 50 MPa in vacuum. In the present work Cu was added as third element to the Ti/Al multilayers and its effect improved the bonding quality. The interface microstructure was studied by scanning and transmission electron microscopy.

1. Introduction

Advanced materials like TiAl-based intermetallics generally require novel joining techniques. Developments in new materials research should be conducted hand-in-hand with the study of joining aspects. For the successful application of new materials, sound joint quality has always been considered a milestone in research and development [1]. Titanium aluminides are one of the most promising advanced intermetallics, potentially attractive for high-temperature structural applications in aerospace and automotive applications due to their high specific strength and good corrosion and oxidation resistance [2,3]. The joining process inevitably plays a crucial role in using TiAl. The bonding of titanium aluminides is more difficult than the bonding of many other engineering alloys due to the high reactivity and the formation of brittle intermetallic phases in the joint. Therefore preventing and/or hindering the formation of brittle phase(s) are the key to joining TiAl. Solid state diffusion bonding with and without interlayer [4–9] and brazing [10–12] has been successfully employed by many different authors in order to join γ-TiAl alloys. The thin interfaces and the lack of structural discontinuity across the interface are the main advantages of these joining techniques. In the last years the diffusion bonding with Ti/Al multilayers has become of particular interest because of the high reactivity of these layers promoting the joining process as demonstrated in previous works [6,7]. Small amount additions of a third element to these multilayers can improve their joinability [8]. The presence of a third element could favour the transformation of the Ti and Al nanolayers into γ-TiAl [13,14]. In this work, copper was selected as a third element since pure Cu fillers and filler alloys containing Cu are frequently used in diffusion bonding and brazing of similar and dissimilar materials [15–19].

Cu is used as an interlayer, as a pure elements or as alloy, in many works [15–19] and therefore is considering as a potential interlayer to join materials, like Ti and aluminium alloys as well like steel and ceramic materials. The reasons for the use of Cu as a interlayer is because: (1) it is a soft metal which deforms and accommodates the stresses caused by the mismatch in thermal expansion coefficients; (2) it has a low price compared to other soft metals which could be employed with similar results (Ag, Au or Pt) and (3) in the form of interlayers, it depress the flow temperature (which enables the use of low diffusion temperature), increase the flowability (which encourages a good contact between the faying surfaces), and could increase the bond strength [18]. It was also found by Deng et al. [20] that a Cu addition improves the ductility in TiAl alloys what is beneficial to the quality and strength of the joint.

In the present study, a γ-TiAl alloy was diffusion bonded using a modified interlayer: a thin film of alternated Ti and Al nanolayers doped with 7.0 at.% of Cu. The microstructural characteristics of the interface were studied and compared to those without a third element.

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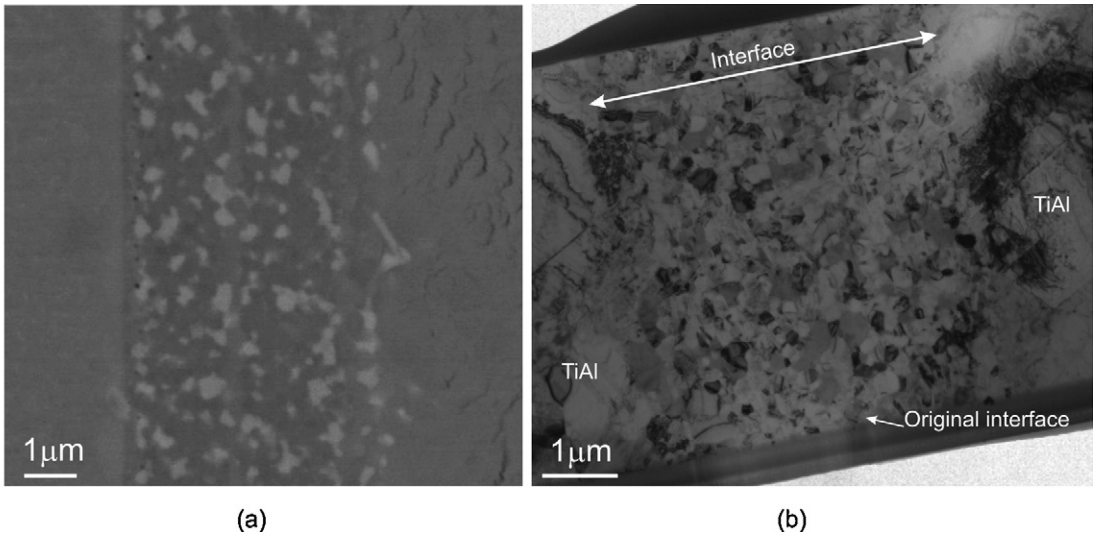

Fig. 1. Interface region of the joint processed at 900 °C/50 MPa/1 h with Ti/Al multilayer doped with Cu, observed by (a) backscattered electron SEM and (b) bright field TEM.

2. Experimental

The γ-TiAl alloy (Ti–48Al–2Cr–2Nb, at.%) used in this investigation has a duplex microstructure. Ti/Al multilayer thin films with chemical compositions close to 50 at.% of Ti doped with 7.0 at.% of Cu were deposited onto the TiAl samples by d.c. magnetron sputtering from two targets (Ti and Al). Small Cu foils were superimposed onto the Ti target. Alternating layers of Al and Ti(Cu) with 4 nm modulation period and 2 μm total thickness were produced. The bottom layer was Ti in order to guarantee a good adhesion to the base γ-TiAl alloy.

Diffusion bonding experiments were performed in a furnace with a vacuum level of about 10^{-2} Pa. The samples were heated to a maximum temperature of 900 °C, and held for 1 h under a pressure of 50 MPa. Heating and cooling rates of 20 °C/min were used in these experiments.

Cross-sections of the joints were prepared using standard metallographic techniques. The interfaces were examined by scanning electron microscopy (SEM), using back-scattered electron contrast. Samples for transmission electron microscopy (TEM) investigation were prepared using focused ion beam (FIB) on a FEI Strata 235 dual beam machine. TEM investigations were made by a Philips CM30 operated at 200–300 kV. Energy dispersive X-ray spectroscopy (EDX) measurements were performed with an EDAX DX-4 system.

The mechanical behaviour/strength of the interface was evaluated by ultramicrohardness tests. The experimental indentation tests were performed in a Fisherscope H100 computer controlled ultramicrohardness testing system. A Vickers indenter was used in all indentation tests, using a 147 mN load during 15 s.

3. Results

The general appearance of the joint processed at 900 °C/50 MPa/1 h with Ti/Al multilayers doped with Cu is presented in Fig. 1. A sound joint without porosity was observed at the entire interface, with the sole exception of a small area at the sample edges. Bright regions distributed across the interface can be seen in the SEM image (Fig. 1(a)); these are copper rich regions. The diffusion of the copper to the base materials is almost inexistent.

The TEM image (Fig. 1(b)) shows that the initial Ti/Al multilayers have evolved to a fine grain structure. In the interface region the grain size varies from 100 to 500 nm.

An EDX line scan was performed across the interface to determine the distribution of Ti, Al, Cr, Nb and Cu elements (Fig. 2). The formation of grains with different chemical compositions along the interface can be confirmed by the diffusion profile presented in Fig. 2. Point measurements on the centre of the interface were performed for different grains represented in Fig. 3(a), and the results are presented in Table 1. An elemental mapping is presented in

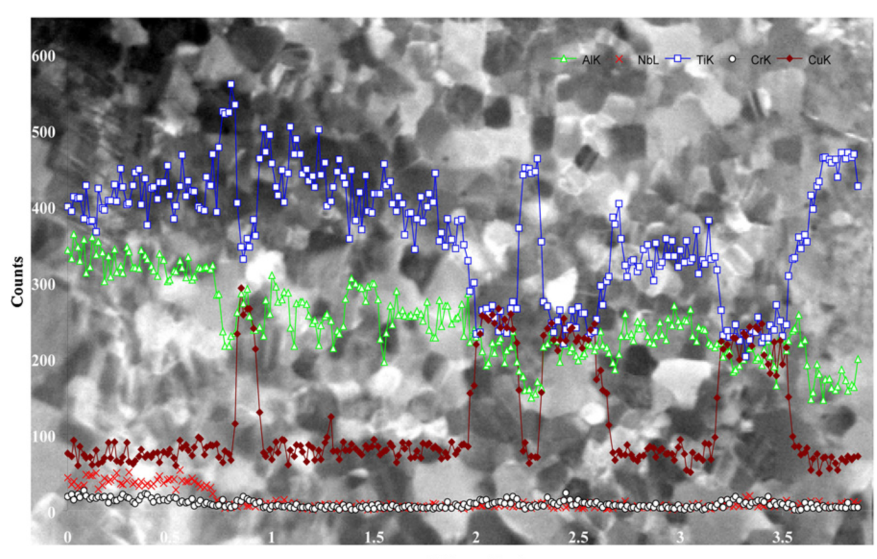

Fig. 2. STEM dark-field image of the interfacial region of the joint processed at 900 °C/50 MPa/1 h with the profile of the line scan.