The Influence of Surface Roughness on Diffusion Bonding of High Nb Containing TiAl Alloy

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Abstract. The solid-state diffusion bonding experiments of the high Nb containing TiAl alloy were successfully carried out at the 1100℃ under a uniaxial pressure of 30MPa for 45min, and the microstructure as well as the shear strength of the diffusion bonding interface with different surface roughness were investigated. The surface roughness was measured by AFM, and the microstructure characterization of interfaces was taken by SEM, EDS, AES. In addition, the bond qualities were evaluated by shear testing at room temperature. The results indicated that the surface roughness is of importance to improve the quality of diffusion bonding joint. Moreover, the white layer microstructure at the bonding interface was found in some samples which was caused by the oxygen content about 2%~3%. Furthermore, the shear teat showed that the shear strength of the joints can achieve 383MPa with the surface roughness is 0.062μm. Meanwhile, the recrystallization phenomenon at the diffusion bonding interface could improve the shear strength.

Introduction

The titanium aluminide alloy is considered to be a potential material for high-temperature structural applications in aerospace and automotive industry. Compared to conventional superalloy, titanium aluminide alloy have several advantages, such as high specific strength, high specific stiffness, good creep and oxidation resistance at elevated temperature[1-6].The operating temperature can enhance to more than 900℃, especially when the element of niobium was added into the conventional titanium aluminide alloy. However, low plasticity and low formability at room temperature restrict the extensive application of the high niobium containing titanium aluminide alloy. Diffusion bonding (DB) technology is one kind of efficient connectivity technology for the high niobium containing titanium aluminide alloy. By choosing appropriate process parameters, the defects of voids and the hot crack can be avoided, hence we can obtain a sound joint through the DB technology. [7-11].

DB technology has been used in many advanced materials, such as ceramics, intermetallic compound (IMC) and stainless steel etc. Cao et al. [12] successfully diffusion bonded the TiAl intermetallics and Ti_3AlC_2 ceramics using Ti-Ni interlayer. They found that the sound joint can be obtained at 920℃/ 60 min due to the interdiffusion of Ti and Al elements. And the highest shear strength of the joint was 151.6MP. Duarte et al. [13] studied the diffusion bonding of the gamma-TiAl alloy using modified Ti-Al nanolayer. Their study indicates that the joining of gamma-TiAl using modified Ti-Al alloy nanolayer doped with Cu at 900℃/50MPa/1h can be obtained without defects due to the ternary TiCuAl phase produced. NAKAO et al. [14] successfully joined the Ti-38Al binary cast alloy using the solid state diffusion bonding method. According to their results, the Time-Temperature-Bonding (TTB) and Time-Temperature-Oxide (TTO) diagrams showed how to make a sound joint at different bonding conditions. Moreover, their tensile result indicated that the tensile strength of the joint at room temperature was about 225MP and the bonding joints fractured at the base metal. Meanwhile, the recrystallization at diffusion bonding interface has improved the joint performance at 1273K with post-bonding heat-treatment. Cam et al. [15] found that the surface roughness was an important factor to the connection of γ-TiAl sheet and the sound bonds could be achieved in primary annealed gamma sheets with ground surface at 1000℃/5MPa/8h.However,they could not evaluate the surface roughness with the professional instruments. These studies mainly focus on the welding parameters and the joint properties of the titanium aluminide alloy. The influence of surface roughness on bonding surface of high niobium containing titanium aluminide alloy is scarcely reported and lucubrated.

A newly developed high niobium containing titanium aluminide alloy, named Ti-45Al-8.5Nb-0.2W-0.1B-0.1Fe-0.1Y was investigated in this paper, which has promising application in aerospace industry. This alloy was bonded by the solid-state diffusion bonding at1100 ℃ under a uniaxial pressure of 30MPa/45min.The surfaces of the bonding specimens were characterized by atomic force microscope (AFM).And the bonding interfaces were characterized using scanning electron microscope (SEM) together with Energy Dispersive Spectrometer (EDS) and Auger electron spectroscopy (AES).The bonding shear qualities were evaluated by a mechanical testing machine at room temperature.

Materials and Experimental Procedures

Materials

The chemical composition (at.%) of high Nb containing TiAl alloy used in this paper is listed in Table1 This alloy was processed as follows: vacuum arc re-melting (VAR)for three times → Hot- isostatic -pressed (HIP) under the conditions of 1280℃/140MPa/240min →canned-forging at 1250℃ with the stain of 10^{-2}/s^{-1}(deformation is 60%) → heat-treatment at 1320℃ and hold for 20min.The final microstructure is near lamellar which is shown in Fig.1.

Table1.The chemical composition of high Nb containing TiAl alloy used.(at.%)

Ti	Al	Nb	W	B	Fe	Y	O
Bal	45.0	8.5	0.2	0.1	0.1	0.1	0.16

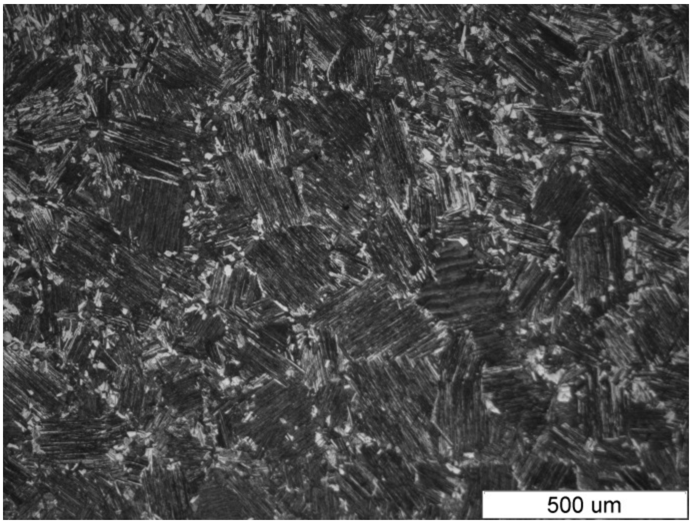
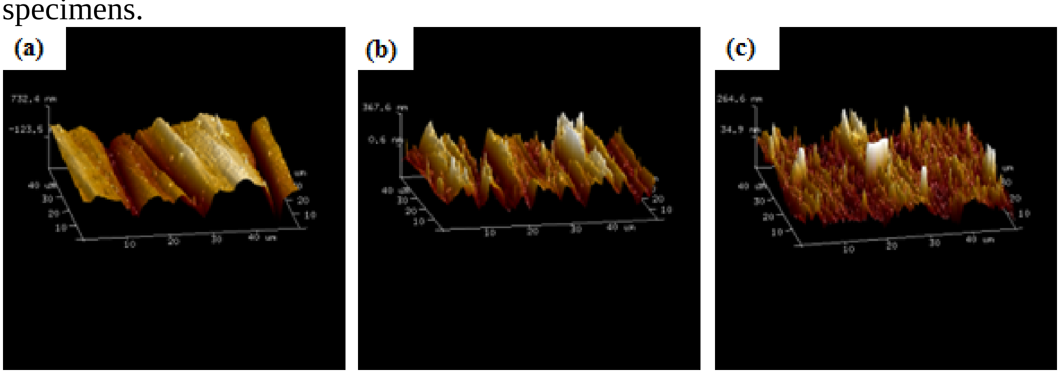


Fig.1 Microstructure of the high Nb containing TiAl alloy

Diffusion Bonding Procedure

The diffusion bonding specimens with a dimension of 8mm×8mm×30mm were electro-discharge machined from the ingot, whose bonding surface were ground by 80#, 80#,240#,400#, 80#,240#,400#,800#,1000# grit emery papers respectively and the specimens were ultrasonic cleaned in alcohol to remove surface dirt. The surface roughness was evaluated by atomic force microscope (AFM)which was 0.261μm（80#）, 0.132μm（400#） and 0.062μm（1000#） respectively.Fig.2 shows the surface morphologies of the diffusion bonding specimens.



(a)Ra=0.261μm (b)Ra=0.132μm (c)Ra=0.062μm

Fig.2The surface morphologies of the diffusion bonding specimens

All diffusion bonding were conducted using a vacuum diffusion bonding furnace under the conditions of 1100℃/30MPa/45minwith the vacuum of 3×10^{-3}Pa. The specimens were heated at the rate of 10℃/min to 1100℃ and held for 10min. Then applied a uniaxial hydrostatic pressure of 30MPato the bonding specimens and held for 45min to obtain a sound joint. The joint was furnace-cooled to room temperature finally. All the joints staggered 2 mm for the mechanical performance test as the Fig.3 (a) shows below.

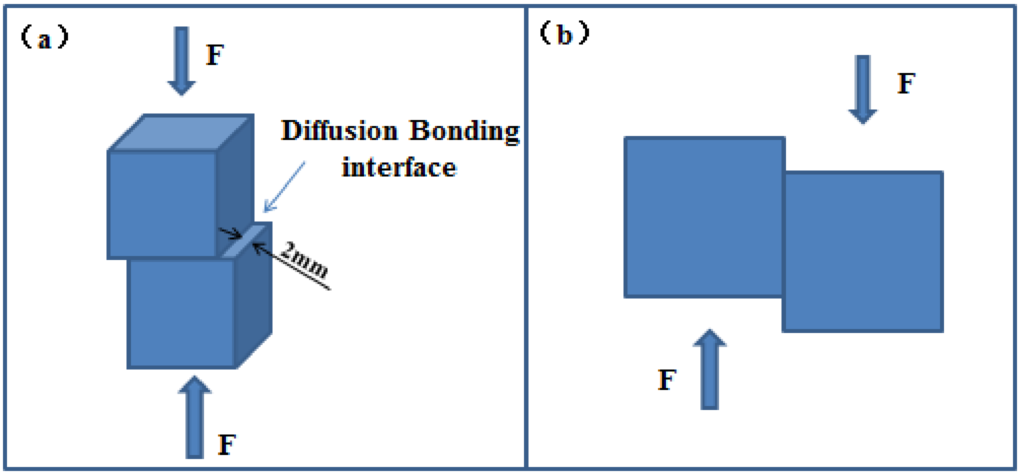


Fig.3 The sample of diffusion bonding and shear test schematic diagrams

Metallographic Examination

The metallographic sample were cut from the sound joint using the electro-discharge machine, ground using the 240#,400#,800#,1000#,1500#,2000#grit emery papers and polished. The cross sections of the bonding sample were etched using the specialty reagent (10% HF, 10%HNO_3, 80%H_2O) to observe microstructure.

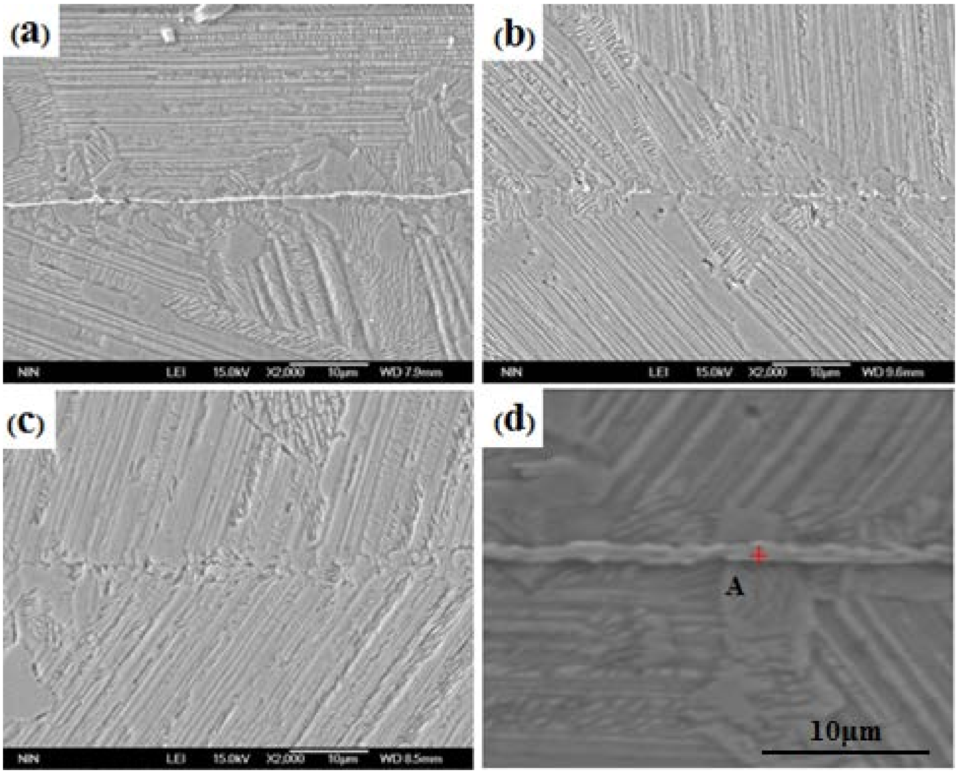
Mechanical Performance Test

In order to evaluate the diffusion bonding qualities of the joints, a nonstandard shear test was devised to measure the shear strength of the bonds. The schematic drawing of shear test is shown in Fig.3 (b) and the compressive shear tests were performed at room temperature on a CMT5205mechanical testing machine with a loading rate of 0.2mm/min. The shear test specimens with the size of $8\times8\times3mm^3$were cut from the overlap joints using an electro-discharge machine.

Results and Discussion

Effect of the Bonding Surface Roughness on the Bonding Interface

A series of diffusion bonding tests were performed to clarify the influence of the surface roughness to microstructure at diffusion bonding interface. Fig. 5 shows the variation of microstructures at bonding interface with different surface roughness at 1100℃using a bonding pressure 30MPa keeping 45 min. A continuous long white layer is observed at the bonding interface (see Fig.4 (a)) and the white layer was separated at the bonding interface when the surface roughness decreased (Fig.4(b)). Finally, the white layer is completely disappeared when the surface roughness is 0.062μm (Fig.4(c)). Besides, the interfacial recrystallization phenomenon could be seen at the diffusion bonding interface beside the white from the Fig.4(d) that is zoomed from Fig.4(a). It is possibly due to the small and nonuniform deformation on the two opposite faces under the load pressure 30MPa which has been reported by Bin Tang et al.[16]As is shown in the Fig.4(b), discontinuous inhomogeneous recrystallization was detected along the bonding interface. Decreasing the surface roughness down to 0.062μm can produce a large amount of recrystallized grains at the bonding interface (Fig. 4(c)).Compared to the bonding condition of 1100℃/30MPa/45min/0.261μm and 1100℃/30MPa/45min/0.132μm,the interfacial recrystallization phenomenon is more obvious with the condition of 1100℃/30MPa/45min/0.062μm. Thus, the white phase was detected in the bonding interface for the sample with larger surface roughness. When the surface roughness is 0.062μm, the white layer disappeared.



(a) 1100℃/30MPa/45min/0.261μm (b) 1100℃/30MPa/45min/0.132μm
(c) 1100℃/30MPa/45min/0.062μm(d) zoomed image of the (a)

Fig.4The variation of SEM microstructure at bonding interface with the different surface roughness

The chemical composition of spot A in Fig.4(d) is shown in Table 2 using the energy dispersive spectrometry (EDS) analysis while the continuous long white phase was extrapolated to α_2(Ti3Al) phase. This phenomenon which mentioned above was caused by the diffusion of the Ti and Al. Meanwhile, small amount of oxygen was conductive to form the α_2 (Ti3Al) phase.

Table2.The chemical composition of the spot A (at. %)

Element	Weight%	Atomic%
Ti	68.49	63.45
Al	16.05	26.40

Effect of Element Content to the α_2 (Ti3Al) Phase

This phenomenon of the α_2(Ti_3Al) phase disappeared gradually and the recrystallization on the diffusion bonding interface are result from the diffusion of the Ti、Al elements and the change of the oxygen content, which were identified by Auger electron spectroscopy(AES) analysis. It is well documented in the literature [16, 17].We can find that the main elements of bonding interface from Fig.5 which also indicates that the white layer phase is the α_2 (Ti_3Al) phase. In addition, the Fig.5 (b) shows the atomic concentrationof the main elements at the bonding interface and the matrix, which indicates that a small amount of oxygen about 2%~3%can promote the formation of the α_2 (Ti_3Al) phase. And we can found the element of Nb was decreased at the bonding interface. As the element of Nb was an inhibition diffusion element. It might to infer that the element of Nb inhibit the elements diffusion of the Ti and Al so that the element of Nb decreased at the bonding interface.

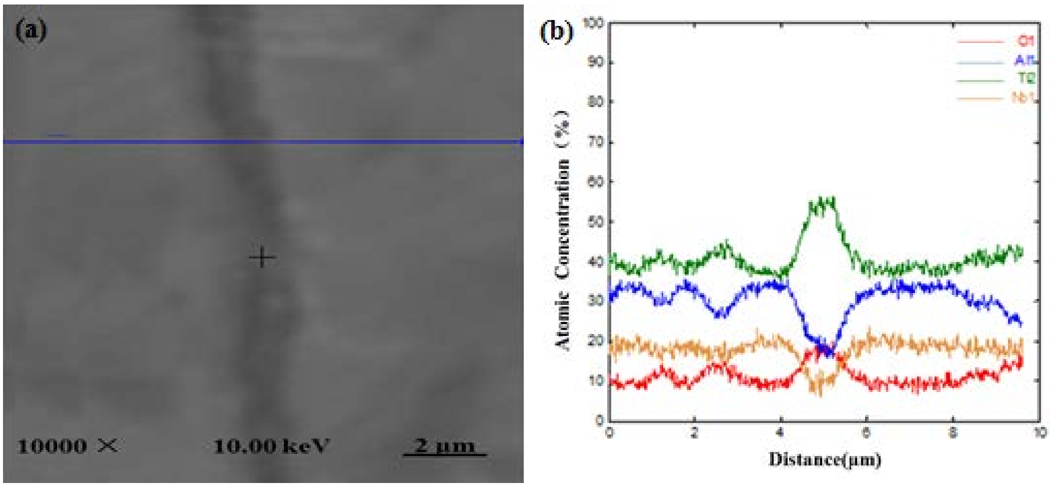


Fig.5 The chemistry composition of bonding interface

Mechanical Properties of the Diffusion Bonding Joint

The mechanical property experiments of the diffusion bonding joints were carried out on a universal mechanical testing machine to evaluate the bonding qualities. The shear strengths of the whole bonding joints under different diffusion bonding conditions were shown in Fig.6.In all cases, the specimens were tested at least three times. As Fig.6 shows, the shear strength of the bonding joint increased with the decreasing surface roughness. It also indicates that the surface roughness of the 0.132μm and 0.261μm are not a sufficient surface roughness for obtaining a sound joint with high strength. We can find that the highest shear strength is 383MPa for the bonded joint which was produced with the parameters 1150℃ /30MPa/45min/0.062μm.This shear strength attains about 98% of the matrix materials. That similar shear strength value were also reported by Cam et al. [15] for diffusion the gamma–TiAl alloys and Bin Tang et al. [18] for the high Nb containing TiAl alloys. The fact that the shear strength of the bonding joints increase which was caused by the disappeared of the α_2 (Ti3Al) phase and the sufficient recrystallization at the diffusion bonding interface.

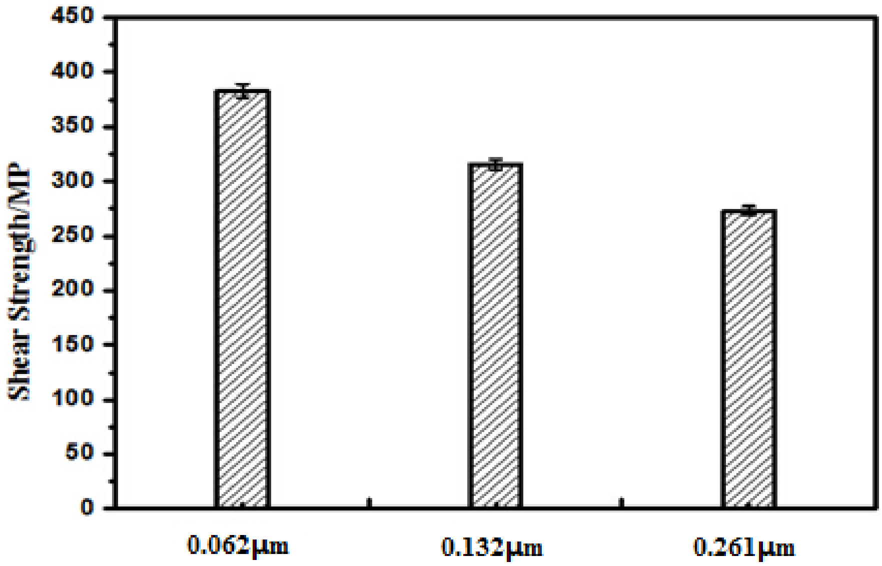


Fig.6 The shear strength of the DB joint with different surface roughness

Conclusions

In this paper, the solid-state diffusion bonding of the high Nb containing TiAl alloy with NL microstructure was studied. And the effect of the surface roughness on the diffusion bonding joint was investigated in details. The recrystallization and the formation of the α_2 (Ti3Al) phase at the diffusion bonding interface has been analyzed. Furthermore, the shear testing at room temperature was performed to evaluate the bonding quality. Present work leads to the several conclusions as follows:

(1) The defect-free bonds of high Nb containing TiAl alloy can be obtained when the diffusion bonding was carried out at 1100℃ under a uniaxial pressure of 30MPa for 45min.

(2) The surface roughness of the materials for diffusion bonding is of importance to improve the quality of diffusion bonding, and with the decrease of the surface roughness, the α_2 (Ti3Al) phase was disappeared which beneficial to the improvement of the performance. When the surface roughness is 0.062μm, the shear strength of the joints can achieve 383MPa.

(3) Itis found that formation of the α_2 (Ti3Al) phase in the bonding interface were induced by the increasing of the oxygen content, in turn degraded performance. However, the recrystallization phenomenon improves the shear strength.

(4) A small amount of oxygen content about 2%~3% can promote the formation of the α_2 (Ti_3Al) phase.

Acknowledgements

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