Phase transformation diffusion bonding of titanium alloy with stainless steel

B. Qin [a],[*], G.M. Sheng [a], J.W. Huang [a], B. Zhou [a], S.Y. Qiu [b], C. Li [b]

[a] *College of Materials Science and Engineering, Chongqing University, 400044, P.R. China*
[b] *National Key Laboratory for Nuclear Fuel and Materials, Sichuan, Chengdu, 610041, P.R. China*

Abstract

Phase transformation diffusion bonding between a titanium alloy (TA17) and an austenitic stainless steel (0Cr18Ni9Ti) has been carried out in vacuum. Relationships between the bonding parameters and the tensile strength of the joints were investigated, and the optimum bond parameters were obtained: maximum cyclic temperature=890 °C, minimum cyclic temperature=800 °C, number of cycles=10, bonding pressure=5 MPa and heating rate=30 °C/s. The maximum tensile strength of the joint was 307 MPa. The reaction products and the interface structure of the joints were investigated by light optical and scanning electron microscopy, energy dispersive spectroscopy and X-ray diffraction. The study indicated the existence of σ phase, Fe_2Ti, Fe–Ti intermetallic and β-Ti in the reaction zone. The presence of the brittle Fe–Ti intermetallic phase lowered both the strength and the ductility of the phase transformation diffusion-bonded joint significantly.
© 2005 Elsevier Inc. All rights reserved.

Keywords: Phase transformation; Diffusion bonding; Titanium alloy; Stainless steel

1. Introduction

Joints of titanium alloys and stainless steel (SS) have wide applications in the chemical processing and nuclear industries [1]. Conventional fusion welding of these two materials can result in the segregation of chemical species, stress concentrations and the formation of brittle intermetallics at the bond interface [2,3]. Extensive work has already been reported on diffusion-bonded joints of titanium alloys and stainless steel [4–7]. However, in most of the previous researches, diffusion bonding was conducted at constant pressure and temperature. Superplastic deformation offers an advantage in the processes

of diffusion bonding [3], because it is possible to break the oxide film, fill any voids on the bonding interface and accelerate the bonding process, especially in the initial stages [8]. In practice, transformation superplastic bonding is generally conducted by using diffusional phase transformation, which occurs as a result of thermal cycling through the transformation temperature under a compressive stress. Superplastic bonding has been used to bond titanium to itself and to dissimilar materials such as the stainless steels. For example, Kato et al. [9] demonstrated that good bonding can be achieved in air, and tensile strengths of 380 MPa and 260 MPa were obtained for Ti/Ti and Ti/SS joints, respectively. For the bonding of a Ti alloy with stainless steel, it was obvious that no plastic deformation occurred in the stainless steel, but the atomic diffusion through the bonding interface would still be accelerated

* Corresponding author. Tel.: +86 13193136720; fax: +86 23 65102466.
   E-mail address: jjj-jenny@163.com (B. Qin).

because of the phase transformation of titanium alloy [8].

In this study, a titanium alloy (TA17) and a stainless steel (0Cr18Ni9Ti) were bonded using phase transformation diffusion bonding (PTDB). The effect of maximum cyclic temperature (T_{max}), minimum cyclic temperature (T_{min}), number of cycles (N), bonding pressure (P) and heating rate (V_h) on the tensile strength (σ) of the diffusion bonds was investigated. The reaction products and the interface structure of the joints were also researched.

2. Experimental procedure

The chemical compositions and room temperature tensile properties of TA17 and 0Cr18Ni9Ti rods are given in Tables 1 and 2, respectively. The phase transformation temperature of TA17 is 888 °C. The TA17 and 0Cr18Ni9Ti rods were cut into specimens of $\Phi 12 \times 30$ mm. The surfaces to be bonded were ground flat by 1000# waterproof abrasive paper and polished by 0.5 μm Al_2O_3 powder. The TA17 was etched for 120 s in a solution of 80% HNO_3 + 20% HF, the 0Cr18Ni9Ti for 10 s in a solution of 15% H_2SO_4 + 15% HCl + 5% HNO_3 + 65% water at room temperature. The etched surfaces were cleaned in ethanol and dried in air prior to diffusion bonding. The diffusion bonding experiments were conducted using a Gleeble 1500 system and the following range of parameters: T_{max} = 850–970 °C, T_{min} = 760–840 °C, N = 2–45, P = 3–10 MPa and V_h = 10–60 °C/s in a vacuum of 5×10^{-2} Pa. In each bonding process, both initial heating rate and the final cooling rate were 5 °C/s, the cyclic cooling rate was 10 °C/s, and the holding time at both T_{max} and T_{min} was 4 s.

Metallographic specimens were cut longitudinally from the bonded assemblies and prepared using conventional metallographic techniques. The TA17 and the stainless steel sides were etched with, respectively, 6% HCl + 2% HF + 92% water and 60% HCl + 20% HNO_3 + 20% water. The microstructure of the TA17/0Cr18Ni9Ti joints was observed in a Zeiss Axiovert-200 light optical microscope. The diffusion-bonded joints were annealed for 1 h at 400 °C before being machined into specimens of $\Phi 10$ mm. The room temperature tensile strengths of the joint were tested

using a hydraulic pressure tensile machine. The fracture morphology of the joint was observed by light optical microscopy and in an Amray-1845 FE scanning electron microscope (SEM). Different regions on the fracture surface were identified using a Rigaku D/MAX X-ray diffraction system (XRD). A Noran Voyager 2 energy dispersive spectroscopy system (EDS) was employed to obtain the overall elemental compositions as well as the concentration profiles across the diffusion zones.

3. Results and discussion

3.1. Effect of bonding parameters

The effects of the various bonding parameters on the ultimate tensile strength of the joint are shown in Fig. 1.

Fig. 1(A) shows the effect of T_{max} on the strength of the joint when the other parameters are kept constant (i.e., T_{min} is 800 °C, N is 30, P is 5 MPa and V_h is 30 °C/s). When T_{max} is in the range of 850–880 °C, σ rises as T_{max} increases. However, at higher temperatures, the joint strength declines. 0Cr18Ni9Ti is an austenitic stainless steel and undergoes no phase transformations in this range. On the other hand, with TA17, there is an $\alpha \leftrightarrow \beta$ phase transformation at 888 °C. Thus, when T_{max} is higher than 890 °C, TA17 undergoes cyclic phase transformations. This has an important influence during PTDB, the joint performance declining because of the ease of brittle phase formation at high temperature [10].

Fig. 1(B) shows the effect on the joint strength of varying the number of cycles, N. When T_{max} is 890 °C, T_{min} 800 °C, P 5 MPa and V_h 30 °C/s, σ reaches a maximum of 307 MPa when N = 10. As the number of cycles increases, so does the bonding time. When $N < 10$, elemental diffusion gradually progresses as the number of cycles multiplies and the strength increases. However, when $N > 10$, brittle phases begin to form and

Table 2
Tensile properties of base materials at room temperature

Alloy	0.2% yield strength (MPa)	Ultimate tensile strength (MPa)	Fracture strain (%)
TA17	660	740	18
0Cr18Ni9Ti	196	541	40

Table 1
Chemical compositions of materials (wt.%)

Alloy	Al	Ni	Cr	Ti	V	Fe	Si	C	N	O	Mn	S	P
TA17	4.5	–	–	Base	2.2	0.069	0.04	0.01	0.023	0.05	–	–	–
0Cr18Ni9Ti	–	8.37	17.22	0.29	–	Base	0.47	0.04	–	–	1.21	0.02	0.03