Materials Science and Engineering A 486 (2008) 171–176

MATERIALS SCIENCE & ENGINEERING A

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Hot pressing diffusion bonding of a titanium alloy to a stainless steel with an aluminum alloy interlayer

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Received 15 June 2007; received in revised form 26 August 2007; accepted 27 August 2007

Abstract

The probability and appropriate processing parameters of hot pressing diffusion bonding (HP–DW) of a titanium alloy (TC4) to a stainless steel (1Cr18Ni9Ti) with an aluminum alloy (LF6) interlayer have been investigated. The microstructure of the bonded joints has been observed by optical microscopy, SEM, XRD and EDX, and the main factors affecting hot pressing and diffusion bonding process were analyzed. The results showed that atom diffused well and no intermetallic compound or other brittle compounds appeared at optimum parameters. The fracture way of joints was ductile fracture. With the increment of bonding temperature, large number of intermetallic compounds such as $FeAl_6$, Fe_3Al, $FeAl_2$ which were brittle appeared along the interface between the stainless steel and the aluminum alloy interlayer, as a result, the quality of joints was decreased significantly and the fracture way of joints was brittle fracture.

Keywords: Hot pressing diffusion bonding; Titanium alloy; Stainless steel; Aluminum alloy

1. Introduction

In recent years, considerable interest has been given to titanium and its alloys because of its unique properties such as high-specific strength and good erosion resistance. With increased use of titanium alloys in aerospace and chemical industries, the effective utilization of titanium alloys needs to develop reliable joining techniques, especially joining techniques of titanium alloys to other materials such as stainless steel which has wide application in industry [1,2]. In some implementations of satellite cooling system, the titanium alloy TC4 (Ti–6Al–4V) is joined to stainless steel (1Cr18Ni9Ti). Owing to the particular configuration of the components, high-precision bonding with specific limits is required. It has been found that high-precision titanium alloy/stainless steel joints with good properties can be achieved by hot pressing and diffusion bonding.

When titanium alloys are directly bonded to stainless steel, various Ti–Fe intermetallic compounds form which embrittle the joint [3–5]. In addition, high internal stresses are formed because of a large difference of linear expansion and heat transmission coefficient between Ti alloy and stainless steel which lead to a bonding crack, so indirect bonding by adding interlayer metal is now largely used. Aluminum alloys have certain erosion resistance and excellent plasticity, therefore, this paper aims to demonstrate the feasibility of hot pressing and diffusion bonding (HP–DW) of TC4 to SS with an interlayer (LF6) and the focus is placed on the relationship of interface microstructure and parameters and the optimum parameters are proposed.

2. Experimental

The chemical compositions of Ti alloy TC4(Ti–6Al–4V), stainless steel (1Cr18Ni9Ti) and the interlayer metal Al alloy LF6 with the thickness of 500 μm used in the present investigation are given in Table 1. The master alloys to be bonded were machined particular configuration as components working in satellite pipe joints, so was the Al alloy to mate them. The master alloy surfaces to be bonded were mechanically polished by 1000# grinding paper, besides; the interlayer metal was etched to remove oxide film which influences bonding process. All surfaces were cleaned in acetone and dried in air prior to bonding.

HP–DW experiments were conducted under a vacuum of 3×10^{-3} Pa. The diffusion bonding equipment was

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doi:10.1016/j.msea.2007.08.076

Table 1
Chemical compositions of TC4 titanium alloy (Ti–6Al–4V), 1Cr18Ni9Ti stainless steel and LF6 aluminum alloy wt.%

	Material													
	C	Si	Mn	Cr	Ni	Ti	Fe	V	Al	N	H	O	Mg	Cu
TC4	0.1	0.2				Bal	0.3	4.5	5.5	0.05	0.02	0.2		
1Cr18Ni9Ti	0.02	1.0	2.0	18	9	1.0	Bal							
LF6		0.5	0.5–0.8				0.5		Bal				5.8–6.8	0.1

high-frequency induction equipment, and the heating rate was set at 2000 °C/min throughout the experiment. After bonding, small blocks were cut for tensile testing which was performed at a nominal strain rate of $3 \times 10^{-4}\ S^{-1}$. The composition analysis of the reaction products and dispersion of elements in the diffusion layer were ascertained by EDX. The microstructures and fracture analysis of bonded joints were conducted by SEM. The kinds and crystal structures of the reaction products were identified from the fracture surfaces of the joints by XRD.

3. Results and discussion

3.1. *Effect of bonding temperature T on strength of HP–DW bonded joints*

The bonding temperature T influences the yield-strength and atomic diffusion of the master alloy. Therefore, it influences the homogeneity of composition and interface microstructure of the bonded joints, so it is the dominant parameter during the bonding process. Effect of bonding temperature T on the tensile strength σ_b of the joints is shown in Fig. 1a. It can be seen that the tensile strength of the bonded joints varies regularly with bonding temperature. When the bonding temperature is 350 °C, the tensile strength of the joints is very low (only 122 MPa).

It can be explained as follows, at such a temperature, yield-strength of SS is fairly high, so contact between the bonded surfaces is very poor, at the same time, thermal excitation is not enough and atomic diffusivity decreases, specimen fracture occurs mostly on the SS/LF6 interface. With increase in bonding temperature from 350 °C to 450 °C, the yield stress of the master alloys decreases and atomic diffusivity increases which result in greater interfacial deformation and easier chemical bonding, as a result, the tensile strength of the joints increases. It can be seen in Fig. 1a that when bonding temperature reaches 450 °C, the tensile strength of the bonded joints increases up to maximum value of 183 MPa. Specimen fracture occurs on the SS/LF6 interface and mostly on interlayer metal LF6, and the fracture way of joint was ductile fracture (as shown in Fig. 2).

With a further increase of bonding temperature to 600 °C, the tensile strength of joints decreases drastically and reaches minimum 34 MPa. Specimen fracture occurs on the SS/LF6 interface and fracture way of joints was entirely brittle fracture (as shown in Fig. 3). When T exceeds 450 °C, the bond strength decreases with increase in the bonding temperature, and this is essential due to a large amount of intermetallic compounds appearing along the SS/LF6 interface, which are mainly responsible for lowering the strength value and reduction in the ductility.

3.2. *Effect of average pressing speed on strength of HP–DW bonded joints*

In present study, average pressing speed was adopted as the measurement of specific bonding stress which influences the deformation rate of the master alloy during the bonding process. Fig. 1b shows the effect of the average pressing speed on the tensile strength of the joints. It can be seen that the

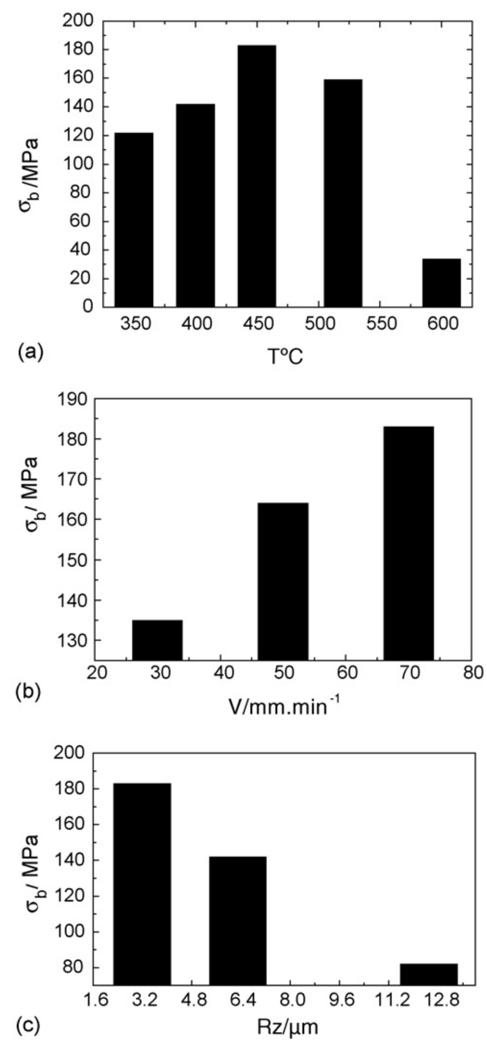

Fig. 1. Effect of the bonding temperature T, the average pressing speed V, and the surface roughness degree of master alloy Rz on tensile strength σ_b of HP–DW bonded joints. (a) Effect of the bonding temperature on tensile strength; (b) effect of the average pressing speed on tensile strength (T = 450 °C); (c) effect of the surface roughness degree of master alloy on tensile strength.