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Experimental study of diffusion welding/bonding of titanium to copper

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In the present study, Ti–6Al–4V alloy was bonded to electrolytic copper at various temperatures of 875, 890 and 900 °C and times of 15, 30 and 60 min through diffusion bonding. 3 MPa uniaxial load was applied during the diffusion bonding. Interface quality of the joints was assessed by microhardness and shear testing. Also, the bonding interfaces were analysed by means of optical microscopy, scanning electron microscopy and energy dispersive spectrometer. The bonding of Ti–6Al–4V to Cu was successfully achieved by diffusion bonding method. The maximum shear strength was found to be 2171 N for the specimen bonded at 890 °C for 60 min. The maximum hardness values were obtained from the area next to the interface in titanium side of the joint. The hardness values were found to decrease with increasing distance from the interface in titanium side while it remained constant in copper side. It was seen that the diffusion transition zone near the interface consists of various phases of βCu_4Ti, Cu_2Ti, Cu_3Ti_2, Cu_4Ti_3 and CuTi.

1. Introduction

Diffusion bonding is a solid-state joining process in which two prepared surfaces are joined at elevated temperature ranging from 0.5 to 0.8 T_m (where T_m is the absolute melting temperature) under pressure [1,2]. The process has an important influence on the design and manufacture of workpieces, since it is of great advantage to bond similar or dissimilar materials [3]. By means of diffusion bonding, it is possible to bond all the materials whose chemical and metallurgical properties are different [4–6]. The process is dependent on various parameters, in particular, time, applied pressure, and bonding temperature to promote microscopic atomic movement to ensure complete metallurgical bond [7].

Almost all materials with compatible chemical and metallurgical properties can be joined by the diffusion bonding process. This welding process has an inherent advantage over conventional welding because it does not involve the formation of unexpected phases at the bond interface that may occur in some advanced materials [8]. The crack, distortion and segregation produced using fusion welding can be avoided using diffusion bonding technology [9]. Welding of titanium and copper, which are characterised by low mutual solubility, is a problem of high priority [10]. Therefore, they are difficult to be bonded through fusion welding methods.

Diffusion bonding has been used successfully to join titanium to stainless steel [11], titanium to steel using a copper base alloy as interlayer [12] titanium to low carbon steel using a silver interlayer [13], pure titanium to hydrogenated Ti–6Al–4V alloys [14], titanium alloy to stainless steel using impulse pressuring in vacuum [15], titanium to titanium using silver and copper interlayers [16], titanium to stainless steel using a nickel interlayer [17], titanium to 304 stainless steel using copper interlayer [18] and Ti–6Al–4V to Cu–10Sn bronze materials [19]. In addition, Kundu et al. [20] joined Ti–6Al–4V to micro-duplex stainless steel, Liu and Feng [21] joined annealed TC21 to titanium alloy, He et al. [22] joined Ti–2.5Al–2.5Mo–2.5Zr to Co–Cr–Mo alloys and again Kundu et al. [23] joined Ti–6Al–4V alloy to micro-duplex stainless successfully through diffusion bonding methods recently.

To the best of the authors's knowledge, there is no work dealing with welding of titanium to copper by diffusion welding was reported in the literature. Titanium to Copper joints may be applied, for example, in cathodes of electrolyzers for copper production the application of the real industry [10]. The present research focused on developing diffusion bonding technique of the titanium to electrolytic copper. For this purpose, titanium and copper materials joined through diffusion welding method.

Hardness and shear strength of the transition zone joints was evaluated in room temperature. Additionally, the morphologies of interface were examined with optical, Scanning Electron Microscopy (SEM) and the elements content was analysed with energy dispersive spectrometer (EDS).

2. Experimental procedure

In this study, Ti–6Al–4V alloy and an electrolytic Grade 99.99% copper (ASTM B49/92) were used for diffusion bonding. Table 1 shows the chemical compositions of Ti–6Al–4V materials. The

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Table 1
Chemical composition of the Ti–6Al–4 V (wt.%).

ASTM standard	Transformation temperatures (°C)		Alloying elements (wt.%)		
	Alpha (α)	Beta (β)	Ti	V	Al
Grade 5	913	890	90.02	4.14	5.84

specimens for the diffusion welding (Ti and Cu) were prepared in the sizes of 10 mm in diameter and 10 mm in length. The prepared specimens were ground with SiC abrasive papers of various grit sizes (240, 400, 800 and 1200) and polished to mirror surface finish using a 1 μm diamond paste. Finally, all the specimens were cleaned by degreasing in acetone.

Diffusion welding was made in an argon atmosphere in the bonding chamber equipment. The experimental work was carried out on a TR2002 02710 U patented diffusion welding equipment shown in Fig. 1. On the other hand, Fig. 2 shows the dimensions of specimen to be welded and the bonded specimens pictures. In order to eliminate the oxidation problem, Ar gas was introduced into the test chamber 5 min before the welding and kept (continued) during welding. 3 MPa pressure was applied during the diffusion bonding. Important diffusion bonding process parameters (bonding temperature and holding time) were identified in Table 2 by carrying out preliminary tests. Heating and cooling rates of 20 °C/min were employed during the heating and cooling cycles. When the bonding process was completed, the specimens were cooled to room temperature in the furnace. Four specimens were made for each bonding parameters. While one of them was used for SEM and hardness measurement, three of them were used for shear test.

After the bonding process, metallographic specimens were cut longitudinally from the bonded joints and prepared using conventional metallographic techniques. Grinding was carried out using 240–1000 grit water-cooled silicon carbide papers and polishing was completed with 1 μm diamond paste, respectively. The Ti side was etched in a solution of 73% H_2O–16% HF–6% HNO_3–5% HCI and the copper side was etched in a solution of kroll reagent at room temperature. In order to examine the quality of the bonding interface, the hardness and shear tests were performed on the welded specimens. The hardness test was performed using a LECO AHM43 microhardness tester and applied. In hardness measurements, a load of 10 g was used and the average of five measurements for each part was taken. A specially testing apparatus was designed to determine bond shear strength (Fig. 3). The shear tests were carried out with SWICK/ROELL device and the averaged values of at least three readings were taken. The tests were carried out at room temperature and at loading speed of 0.3 mm/min. The joints microstructure and compositions were characterised using SEM (VEGA T85135 and JEOL JSM 6335S) equipped with an EDS.

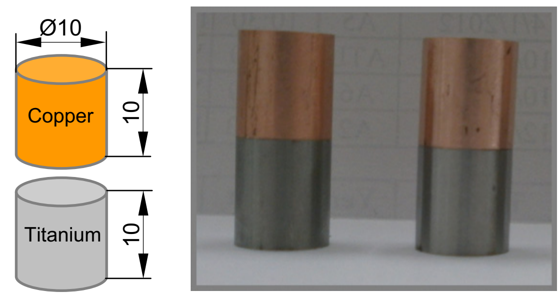

Fig. 2. Photographs and dimensions of *t* welded specimens.

Table 2
Diffusion bonding parameters used in this study.

Material	Temperature (°C)	Welding time (min)
Ti–Cu-1	875	15
Ti–Cu-2	875	30
Ti–Cu-3	875	60
Ti–Cu-4	890	15
Ti–Cu-5	890	30
Ti–Cu-6	890	60
Ti–Cu-7	900	15

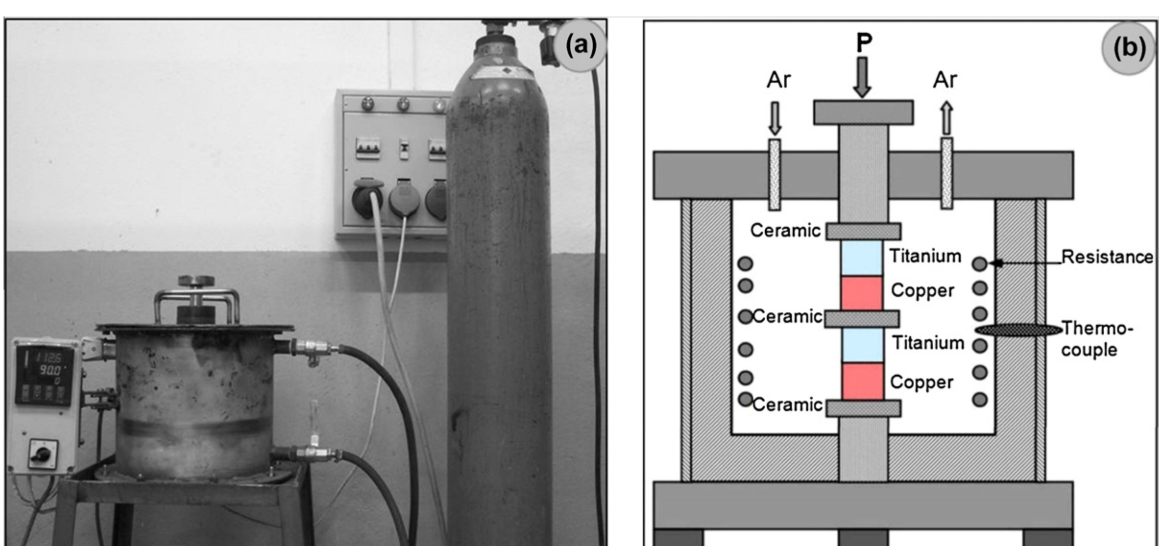

Fig. 1. Illustration of diffusion welding equipment (a) photo and (b) schematic.