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Study on cold metal transfer welding–brazing of titanium to copper

R. Cao *, Z. Feng, Q. Lin, J.H. Chen *

State Key Laboratory of Gansu Advanced Non-ferrous Metal Materials, Lanzhou University of Technology, Lanzhou 730050, PR China
Key Laboratory of Non-ferrous Metal Alloys of Ministry of Education, Lanzhou University of Technology, Lanzhou 730050, PR China

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ABSTRACT

3 mm Pure titanium TA2 was joined to 3 mm pure copper T2 by Cold Metal Transfer (CMT) welding–brazing process in the form of butt joint with a 1.2 mm diameter ERCuNiAl copper wire. The welding–brazing joint between Ti and Cu base metals is composed of Cu–Cu welding joint and Cu–Ti brazing joint. Cu–Cu welding joint can be formed between the Cu weld metal and the Cu groove surface, and the Cu–Ti brazing interface can be formed between Cu weld metal and Ti groove surface. The microstructure and the intermetallic compounds distribution were observed and analyzed in details. Interfacial reaction layers of brazing joint were composed of Ti_2Cu, TiCu and $AlCu_2Ti$. Furthermore, crystallization behavior of welding joint and bonding mechanism of brazing interfacial reaction were also discussed. The effects of wire feed speed and groove angle on the joint features and mechanical properties of the joints were investigated. Three different fracture modes were observed: at the Cu interface, the Ti interface, and the Cu heat affected zone (HAZ). The joints fractured at the Cu HAZ had higher tensile load than the others. The lower tensile load fractured at the Cu interface or Ti interface was attributed to the weaker bonding degree at the Cu interface or Ti interface.

1. Introduction

Hybrid structures of dissimilar metals have been gradually appreciated in national defense and civil industrial fields, such as aerospace, shipbuilding, energy and electric power industry [1]. Hybrid structure of Ti/Cu dissimilar alloys not only satisfies the requirements of heat conduction, electrical conduction, wear resistance and corrosion resistance, but also meets demand of light weight and high strength. However, fusion joining of titanium and copper has a metallurgical challenge because of the great differences in their chemical and physical properties, and mass of brittle Ti–Cu intermetallic compounds (IMCs) are formed at elevated temperatures seriously degrading the mechanical properties of the joints [2–6]. It is necessary to control effectively formation and growth of Ti–Cu IMCs. Solid-state welding methods, e.g. explosive welding and friction welding, have been used to make Ti/Cu dissimilar metals joint, but the shape and size of such solid-state joints are extremely restricted [7–9].

In recent years, welding–brazing methods have been developed for dissimilar metals with large difference in melting point, e.g. tungsten inert gas (TIG) arc welding–brazing of Al to steel [10,11], laser welding–brazing of Ti to Al [12] and electron beam self-melting brazing of Ti to Cu [13]. In the welding–brazing process, the metal with low melting point and filler metals were molten and mixed to form a fusion welding joint, the metal with high melting point was little molten or maintain solid, and the liquid filler metal wetted and spread on the metal with high melting point to form a brazing joint.

Nowadays, Cold metal transfer (CMT) process is a new technique and becomes a hot research field in dissimilar materials welding [14,15]. CMT welding–brazing of Al to steel [16,17], CMT welding–brazing of Al to Ti [18] have been carried out in recent years. In this study, commercially pure titanium TA2 and commercially pure copper T2 were joined using a 1.2 mm diameter ERCuNiAl (AWS A5.7/A5.7 M) copper wire through CMT welding–brazing. Ti/Cu CMT welding–brazing butt joint was composed of Cu–Cu welding joint in the Cu side and Cu–Ti brazing joint in the Ti side. Three different configurations of Cu/Ti butt joints with various welding bevel grooves were adopted. The influence of different groove angles of Cu side and wire feed speed on the features and mechanical properties of the joint were investigated. After welding, the weld appearance, tensile load, crystallization behavior and bonding mechanism of joints were analyzed and discussed.

2. Experimental details

2.1. Materials

The materials used in the study include 3 mm thick commercially pure titanium TA2 sheet and 3 mm thick commercially pure

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* Corresponding authors at: Key Laboratory of Non-ferrous Metal Alloys of Ministry of Education, Lanzhou University of Technology, Lanzhou 730050, PR China. Tel.: +86 931 2973529; fax: +86 931 2976578.

E-mail addresses: caorui@lut.cn (R. Cao), zchen@lut.cn (J.H. Chen).

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copper T2 sheet. The corresponded compositions, per the manufacturer's data sheet, are given in Table 1. Copper wire ERCuNiAl (AWS A5.7/A5.7 M) having a diameter of 1.2 mm was used in this study. Its chemical composition is shown in Table 2.

2.2. Welding procedure

The Ti and Cu sheets were machined to rectangular strips of 100 mm × 50 mm × 3 mm and designed as the butt joint configuration, as shown in Fig. 1. The V shape grooves with different groove angles were machined from the base metals. Three different configurations of Cu/Ti butt joints (*joint I* (Cu–T2–60°, Ti–TA2–30°), *joint II* (Cu–T2–45°, Ti–TA2–30°), *joint III* (Cu–T2–30°, Ti–TA2–30°)) with various groove angles were adopted in the experiments. In order to control effectively formation and growth of Ti–Cu IMCs and decrease the molten titanium, the wire was deviated from the edge of Cu sheet edge, as shown in Fig. 1.

The two sheets were degreased by acetone and polished by abrasive cloth first. Ti sheets were cleaned with HF 5% + HNO_3 35% aqueous solution for 10–20 min, then wiped and rinsed with ethanol and tap water. And the Cu sheets were wiped and rinsed with ethanol and tap water.

The CMT welding–brazing joining was carried out using TPS-3200 type CMT welding procedure. The welding parameters were listed as follows: welding speed (v_w) of 6 mm/s, wire feed speed (v_f) of 7.0–9.5 m/min, welding current (I_w) of 158–223 A, welding voltage (V_w) of 14.7–20.3 V, 99.99% argon shielding gas flow rate of 17 L/min. The various welding variables and the mechanical properties of Ti/Cu CMT butt joints were given in Table 3.

2.3. Characterization methods

After welding, in order to investigate the mechanical properties of the Ti/Cu CMT butt joints, tensile tests were carried out according to ISO 4136-2012 [19]. Three or two tensile specimens depicted in Fig. 2 were cut off from each weldment and tested on a WDW-100E type universal testing machine at the tensile speed of 1 mm/min at room temperature. Average tensile load of tensile specimens was taken to estimate the mechanical property of the joint.

According to ISO 9015-1: 2001 [20], the Vickers micro-hardness of the Ti/Cu butt joints was measured by the HX-1000 micro-hardness testing machine with a load of 200 gf for 5 s.

To study the microstructure and bonding mechanism of Ti/Cu CMT butt joint, the cross-sections of the specimens were prepared and examined. The microstructures of the welded joints and the IMCs were observed and analyzed by scanning electron microscope (i.e., Quanta FEG-450) equipped with energy dispersive X-ray spectrometer (EDS).

3. Results

3.1. Effects of wire feed speed and groove angle on the joint features

Table 2
Nominal chemical composition of ERCuNiAl copper wire (wt.%).

Alloy	Al	Ni	Pb	Fe	Mn	Cu
ERCuNiAl	8.0	6.0	0.038	3.0	1.0	Bal.

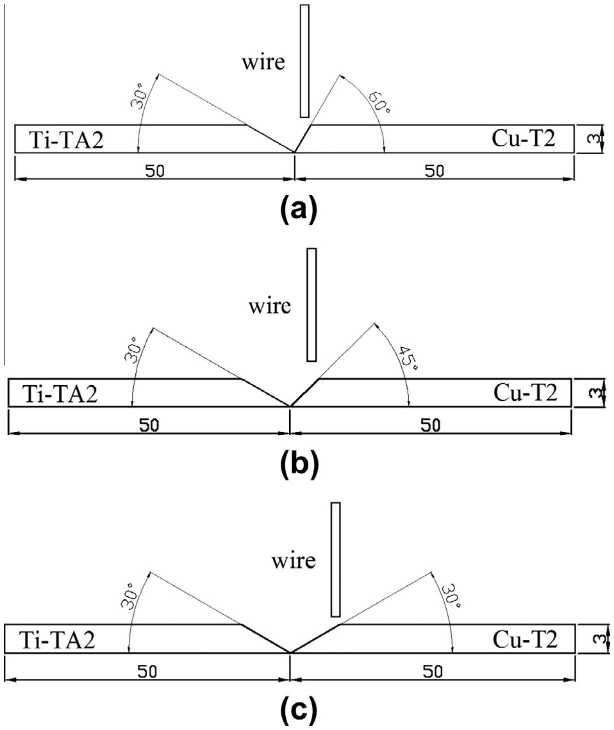

Fig. 1. Schematic diagram of Ti/Cu CMT butt joint: (a) *joint I* (Cu–T2–60°, Ti–TA2–30°), (b) *joint II* (Cu–T2–45°, Ti–TA2–30°), and (c) *joint III* (Cu–T2–30°, Ti–TA2–30°) (mm).

Fig. 3 shows the macroscopic cross-sections of three types of Ti/Cu CMT butt joints with different welding parameters listed in Table 3. For *joint I* (Cu–T2–60°, Ti–TA2–30°), at the v_f of 7.0 m/min and 8.0 m/min (I_w of 158 A and 184 A), the Cu base metal near Cu groove surface was not molten due to the low weld heat input and the high thermal conductivity coefficient of copper (359.2 $Wm^{-1}K^{-1}$ [21]). For these low weld heat input, welding joint cannot be formed at the Cu groove side. However, the Cu–Ti interface between the liquid filler metal and the Ti groove surface can be successfully brazed, as shown in Fig. 3(a_0) and (b_0). Increasing the v_f to 9.0 m/min (I_w = 210 A), the welding–brazing joint was formed except only the root part of the Cu groove which was not fully molten, as shown in Fig. 3(c_0). At the high v_f of 9.5 m/min (I_w = 223 A), the excellent joint was formed as shown in Fig. 3(d_0). Based on Fig. 3(a_1–d_1), it was found that the formation process of *joint II* with groove angle of (T2–45°, TA2–30°) was similar to that of the *joint I*. But for *joint III* with lower groove angle on Cu side (T2–30°, TA2–30°), even at the low v_f of 7.0 m/min and 8.0 m/min (I_w of 158 A and 184 A), the liquid filler metal spread on the Cu groove surface to form the Cu–Cu weld metal. However, it still incompletely spread on the Ti groove surface, as shown in Fig. 3(a_2) and (b_2). Increasing the v_f to 9.0 m/min (I_w = 210 A), Ti groove surface was wetted by the molten Cu metal, yet the root region of the Cu groove was still incompletely molten, as shown in Fig. 3(c_2). Further increasing the v_f to 9.5 m/min (I_w = 223 A), the liquid filler metal spread on the Cu groove surface, and mixed with molten Cu

Table 1
Nominal chemical compositions of commercially pure titanium TA2 and commercially pure copper T2 (wt.%).

Materials	Bi	Pb	Fe	Mn	C	N	S	P	O	H	Ti	Cu
TA2	–	–	0.30	–	0.10	0.05	–	–	0.25	0.0015	Bal.	–
T2	0.002	0.005	–	–	–	–	0.005	0.03	–	–	–	Bal.