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Dissimilar copper-aluminum joint processed by low-temperature nickel electroplating

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ABSTRACT

This study proposed a low-temperature method to form joints between copper (Cu) and aluminum (Al) by electroplating nickel (Ni) at temperatures below 50 °C. Both the Cu/Ni and Al/Ni interfaces were characterized by transmission electron microscopy (TEM). The Cu/Ni interface was an approximately 60-nm-wide layer of an unlimited substitutional solid solution of Cu and Ni, whereas a 20-nm-wide layer of a BCC-structured AlNi intermetallic compound (IMC) was observed at the Al/Ni interface on the Ni side. The joined samples were heat-treated at 200 °C for durations of 5 h to 1000 h, and the joint strength did not degrade after isothermal aging. No further growth of the intermetallic compound was observed at the Al/Ni interface during the isothermal aging process.

1. Introduction

In recent years, joining Cu and Al has attracted considerable attention because in addition to exhibiting excellent electrical and thermal properties, the two materials also exhibit good mechanical performance and are lightweight for use in industrial products (Marya and Marya, 2004). For example, the partial substitution of Cu with Al in wires, cables and contact sites is frequently observed. The benefit of this hybrid Cu-Al structure is that the original structure undergoes a mass reduction with only a small sacrifice in the electrical conductivity (Bergmann et al., 2013). An additional reason for joining Cu and Al is for cell-to-cell and cell-to-bus bar interconnectors for battery module assemblies (Acarer, 2012). Foil conductors in transformers, capacitor and condenser foil windings, refrigeration tubes, heat exchanger tubes, and tube sheets are other common applications of Cu-Al joints (Mehta and Badheka, 2016a).

Joining Cu and Al poses a significant challenge due to the significant differences in the properties of the two materials, such as the melting point, thermal conductivity and coefficient of thermal expansion (Xue et al., 2014). Laser welding is a commonly used method for joining Cu and Al, but it is characterized by the formation of brittle, low-strength and high-electrical resistance intermetallic compounds (IMCs), such as Al_2Cu, AlCu and Al_4Cu_9, which results in an increased susceptibility to failure (Zuo et al., 2014). Moreover, the narrow beam dimensions make laser welding extremely sensitive to the joint fit-up tolerance, which makes it challenging to obtain high-quality welds (Suder et al., 2011). The low absorption of Al and Cu, particularly at a laser wavelength of 1 μm, is another limitation for infrared laser light (Stritt et al., 2014). Otten et al. (2016) investigated the electron beam welding of Cu to Al, and the Al_2Cu phase resulted in the brittle fracture of the welded joints. Whereas fusion welding produces brittle welding seams due to the formation of IMCs, certain solid-state joining methods are advantageous because the processes that they utilize occur well below the melting temperatures of the two joining materials. Friction stir welding (FSW) has been proven to be an effective method to join Cu and Al. Mehta and Badheka (2015) observed that the properties of the dissimilar friction stir welding of Cu-Al joints were influenced by the tool design and process parameters, such as the tool pin offset, welding speed and axial plunge load. Avettand-Fènoël et al. (2016) investigated the microstructure and mechanical performance of Cu-Al joints obtained by linear friction welding and proposed a phenomenological mechanism of material flow. Mehta and Badheka (2016b) reported the effects of the tilt angle on the properties of a Cu-Al joint processed by FSW and proposed a hybrid approach of assisted heating and cooling for the FSW based on

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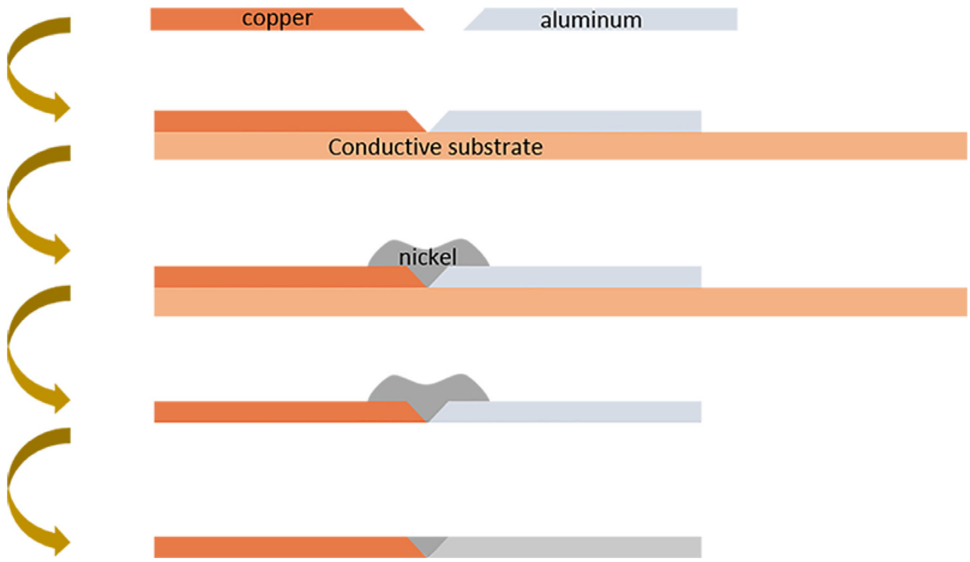

Fig. 1. Schematic diagram of the joining process.

Table 1
Compositions and contents of T2 Cu and 5052 Al alloy.

T2 Cu		5052 Al alloy	
Composition	Content (%)	Composition	Content (%)
Bi	0.001	Si	≤0.25
Sb	0.002	Cu	≤0.1
As	0.002	Mg	2.2–2.8
Fe	0.005	Zn	≤0.1
Pb	0.005	Mn	≤0.1
S	0.005	Cr	0.15–0.35
		Fe	≤0.4

Table 2
Parameters for the electrochemical degreasing solution and process.

Parameter	Value
NaOH content	20 g/L
Na_2CO_3 content	15 g/L
Na_3PO_4 content	30 g/L
Na_2SiO_3 content	10 g/L
Temperature	40 °C
Current density	2 A/dm^2
Duration	30 S

Table 3
Parameters for the Ni electroplating solution and process.

Parameter	Value
$Ni(SO_3NH_2)_2{\cdot}4H_2O$ content	300 g/L
H_3BO_3 content	50 g/L
$NiCl_2$ content	60 g/L
Temperature	45–50 °C
Current density	5–10 A/dm^2
Magnetic stirring	400 r/min

cooling with water; this hybrid approach significantly improved the tensile strength of the weld (Mehta and Badheka, 2017). Zhang et al. (2016) developed friction stir spot brazing (FSSB) as a modified process of friction stir spot welding (FSSW) to achieve the joining of Cu and Al. Thus far, explosive welding (Acarer, 2012), ultrasonic welding (Yang and Cao, 2015), electromagnetic pulse welding (Marya and Marya, 2004; Wu and Shang, 2014), and cold welding using the equal channel angular extrusion (ECAE) process (Zebardast and Taheri, 2011) have been proposed to join Cu and Al. However, localized high-temperature regions inevitably form at the interface when using these techniques, which will result in the nucleation and growth of Cu-Al IMCs at temperatures above 120 °C (Ma et al., 2015); these IMCs are brittle and have a high electrical resistance because they have nonmetallic covalent bonds.

This paper proposes a low-temperature joining method for Cu and Al based on Ni electroplating at 45–50 °C, and the results show that the Cu and Al strips were successfully joined. Both the Cu/Ni and Al/Ni interfaces were characterized by TEM, and the tensile strength of the joint was measured before and after the aging test. Furthermore, the fracture mode observed during the uniaxial tensile test was examined.

2. Experimental procedure

2.1. Joining Cu and Al strips

Ni electroplating was used to join 0.5-mm-thick Cu (T2) and Al alloy (5052) strips; the elemental compositions of the two materials are listed in Table 1. Fig. 1 shows a schematic diagram of the joining process. The Cu and Al strips were beveled to form a 45° wedge, and two wedges were fixed on a conductive substrate of T2 Cu with a thickness of 2 mm to form a 90° groove. For convenience, Scotch tape was used to enlace the strips onto the conductive substrate, and the strips were simultaneously insulated, thereby exposing the surface of the groove to be electroplated with Ni. Electrochemical degreasing of the groove surface is essential to achieve a reliable interfacial bonding between Cu/Ni and Al/Ni. The chemical formulas and process parameters are listed in Table 2. After washing the groove surface with deionized water, the groove was soaked in 10%-volume fraction dilute hydrochloric acid for 10 s to remove the oxide film on the Cu and Al surfaces. After the washing was repeated with deionized water, the strips were connected to a circuit as the cathode while Ni was used as the anode. The experiment was conducted in a magnetic stirrer at 45–50 °C. The process parameters and chemical formula of the electroplating solution are shown in Table 3. During the electroplating process, Ni atoms were continuously deposited on the groove surface until the surface was completely covered. Finally, the surface was mechanically polished to remove the excess Ni on the groove after the joint was formed. Twenty-five samples were prepared, and all were successfully joined.