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Interfacial structure and properties of Cu/Al joints brazed with Zn-Al filler metals

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ABSTRACT

Seeing that opinions vary, no unanimous conclusion has been drawn on Cu side interfacial structure and its relationship with the mechanical properties of Cu/Al joints brazed with Zn-Al filler metals, XRD, SEM and HAADF-STEM were used to accurately reveal the Cu side interfacial structure and the mechanism concerned. The relationship among the brazing process, interfacial structure and mechanical properties of the joints was systematically studied. The following phenomena and principles were newly found and clarified. The Cu side interfacial structure are uncertain and dependent on brazing parameters, especially cooling rate after brazing, in addition to the composition of Zn-Al filler metal. High cooling rate promotes the formation of CuZn and $Al_{4.2}Cu_{3.2}Zn_{0.7}$ compounds, while slow cooling rate is beneficial for the formation of Cu-Al interfacial compounds at the Cu side interface. Increasing brazing temperature or lengthening holding time enhances the dissolution of base metals, which results in the increase of Al and Cu contents at the Cu side interface, thus promoting the formation of $CuAl_2$ compound. Besides, increasing Al content in Zn-Al filler metal also promotes the formation of $CuAl_2$ compound by directly increasing Al content at the Cu side interface. The significant differences in joint strength are caused by the differences of Cu side interfacial compounds essentially. When the thin CuZn and $Al_{4.2}Cu_{3.2}Zn_{0.7}$ layers exist at the Cu side interface, the brazed joint possesses high shear strength. On the contrary, the formation of Cu-Al compound layers at the Cu side interface, especially $CuAl_2$, will severely degrade the joint strength.

1. Introduction

Owing to their high specific strength, light weight, low cost and high electrical conductivity, Cu/Al compound structures are widely used in electronics, heat exchanger and refrigeration industries [1–3]. Among a variety of techniques, brazing has been adopted as a reliable method for joining Cu and Al, wherein Zn-Al alloys are recognized as a promising filler metal [4–6]. However, strong interfacial reaction would happen between solid Cu base metal and liquid Zn-Al filler metal due to the existence of Al in Zn-Al filler metal. Particularly, Cu and Al are liable to form intermetallic compounds (IMCs), such as Cu_9Al_4, Cu_3Al_2, Cu_4Al_3, CuAl, and $CuAl_2$ [7]. The brittle Cu-Al compounds at the Cu side interface severely affected the properties of the Cu/Al joints [8]. Therefore, the interfacial behavior, structure and mechanism concerned of Cu/Al brazed joint have always attracted great attention, which are of much concern to the design of the brazing filler metal and optimization for brazing process.

Some scholars have studied the effect of composition of Zn-Al filler metal on the Cu side interfacial structure [9–14]. However, the current research conclusions concerned have been inconsistent even contradictory. Even using the same composition of Zn-Al filler metal, there exist great differences in Cu side interfacial structure and joint strength when different brazing method is applied. Used torch brazing to join Cu and Al with Zn-22 wt% Al filler metal, Ji et al. found that the Cu side interfacial structure was $Cu/CuZn_3/CuAl_2$ and the shear strength of brazed joint was about 68 MPa [13]. Correspondingly, when Cu/Al joint was brazed by furnace brazing with Zn-22 wt% Al filler metal, a completely different Cu side interfacial structure of $Cu/Cu_9Al_4/CuAl/CuAl_2$ was obtained, and the shear strength of brazed joint was only 42.5 MPa [11]. The reason for the difference in Cu interfacial structure might be due to the different brazing parameters for different brazing methods. Moreover, when the same brazing method was used to braze Cu/Al, the different interfacial compounds might also be obtained for different scholars even with the same composition of Zn-Al filler metals, which resulted in much difference in bonding strength of the joints. Ji et al. used torch brazing technique to join Cu and Al with Zn-*x*Al filler metals (x = 2, 15, 22 wt%), and studied the effect of Al content on the

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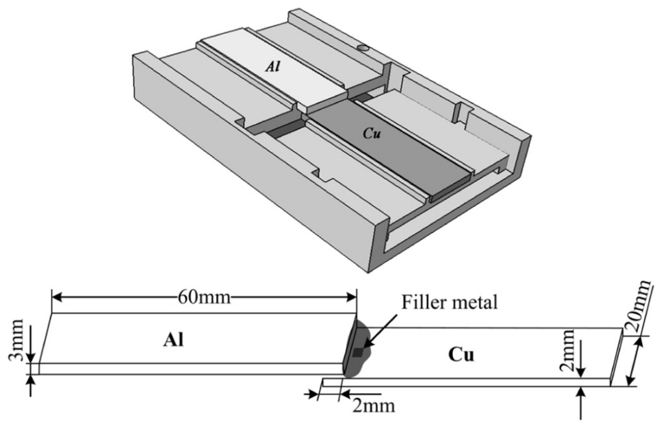

Fig. 1. Schematic representation of brazed specimens for shear testing.

Table 1
Melting points of the Zn-Al filler metals.

No.	Filler metal/wt%	T_S/°C	T_L/°C
Sample 1	Zn-15Al	382	457
Sample 2	Zn-22Al	407	490
Sample 3	Zn-28Al	423	505

Note: *Ts*—solidus temperature, T_L—liquidus temperature.

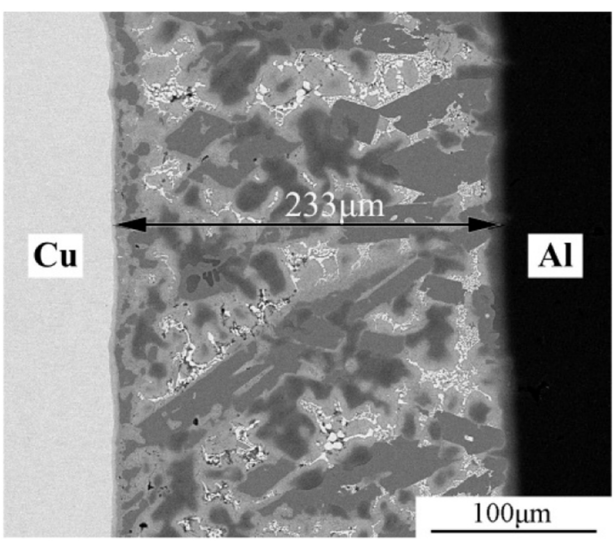

Fig. 2. Microstructure of brazed joint with water-quenched cooling.

Cu side interfacial structure of Cu/Al joints. It was found that with the increase of Al content, the Cu side interfacial structure changed from Cu/$CuZn_3$ to Cu/$CuZn_3$/$CuAl_2$. The shear strength of Cu/Al joint brazed with Zn-15 wt% Al filler metal reached 88 MPa [15]. However, when Zhang et al. also adopted torch brazing method to braze Cu/Al with Zn-15 wt% Al filler metal, the Cu side interfacial structure was observed to be Cu/$CuAl_2$. As a result, the shear strength of the joint was only about 44 MPa [16]. This big difference might be attributed to the uncontrollability of the torch brazing method in brazing parameters, such as brazing temperature, holding time and cooling rate after brazing. It should be noticed that the previous investigations on the Cu side interfacial structure of Cu/Al brazed joints were inferential only based on SEM and/or EDS.

As mentioned and analyzed above, the root cause of the difference in Cu side interfacial structure and properties of Cu/Al joints brazed with Zn-Al filler metals may be ascribed to the different brazing parameters for both different and same brazing methods, i.e., the Cu side interfacial structure and properties of Cu/Al brazed joints may be closely related to the brazing parameters in addition to the composition of Zn-Al filler metal. Based on such a background, in this paper, XRD, SEM and HAADF-STEM (high angle annular dark field-scanning transmission electron microscope) were used to accurately reveal the Cu side interfacial structure and the formation mechanism. Selected the Zn-Al filler metal composition and the brazing process parameters, such as, brazing temperature, holding time and cooling rate after brazing as influence factors, the relationship among the influence factors, interfacial structure and mechanical properties of the Cu/Al joints brazed with Zn-Al filler metals was systematically studied. Considering the importance of the brazing process, furnace brazing method was adopted to braze Cu and Al dissimilar metals, so that the brazing parameters can be accurately controlled.

2. Experimental

The materials used in the present study were pure aluminum (1060) and pure copper (T2). The Al and Cu samples supplied for the brazing were machined into plates with dimensions of 60 × 20 × 3 mm and 60 × 20 × 2 mm, respectively. The bonding strength of brazed Cu/Al joints with an overlap length of 2 mm was evaluated. Fig. 1 shows the geometry and dimensions of the brazing specimens subjected to shear testing. The contaminants layers that adhere to the surfaces of the two samples should be removed using the following procedures: I. the surfaces were ground with SiC paper down to grade 1000. II. the samples were immersed in 10% (*V*/V) HNO_3 and 0.25% (V/V) HF at room temperature for 5 min. III. the samples were rinsed in cold water and subsequently dried.

The compositions of filler metals used in this study were listed in Table 1. Pure Al (99.995% purity) and 99.999% purity Zn were used in the study to prepare a series of Zn-Al alloys. The raw materials were prepared with salt bath melting process in crucible furnace. In order to get a homogeneous composition within the filler metals, the alloys were remelted at least 3 times. The thermal analysis of the alloys was measured by differential thermal analysis (DTA) technique under high purity nitrogen. Non-corrosion AlF_3-CsF flux, whose melting temperature ranges from 415 to 488 °C, was used to eliminate oxides formed on Al surface and further help the molten solder to spread uniformly on the surface. Cu and Al specimens were joined using argon shielded furnace brazing. To form a sound joint, the brazing temperature should about 30 °C above the liquidus of brazing alloys. Taking into consideration the melting points of Zn-Al filler metals, the brazing temperatures of furnace brazing were set to 520, 540 and 560 °C. Additionally, the heating rate was set at 40 °C/min, and holding time of 40, 80, 120, 160 s were used. After brazing, Cu/Al joints were taken out of the brazing furnace, and then cooled in air and water, respectively.

Shear tests were conducted using a tensile testing machine at a tensile speed of 1 mm/min. Interfacial microstructures near Cu substrate and fractured surfaces were investigated by FEI Quanta 250 scanning electron microscope (SEM) equipped with energy dispersive spectrometer (EDS). The phase constituents of the interfacial zone near Cu substrate were analyzed by means of X-ray diffractometer. The aluminum substrate of the Al/Cu joint was firstly removed during XRD sample preparation. Then, the remaining joint was polished gradually by SiC paper and the XRD analyses were performed continuously in the polish process until the phases were detected. The high angle annular dark field-scanning transmission electron microscope (HAADF-STEM) was used to reveal the Cu side interfacial structure and composition analysis.

3. Results and Discussion

3.1. Effect of Zn-Al Filler Metal Composition

Furnace brazing Cu/Al dissimilar metals was performed using Zn-xAl filler metals (x = 15, 22, 28, wt%) at 540 °C for 40 s. Then, the