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Effect of Ni Content on Mechanical Properties and Corrosion Behavior of Al/Sn–9Zn–xNi/Cu Joints

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The effects of Ni content on the microstructure and the wetting behavior of Sn–9Zn–xNi solders on Al and Cu substrates, as well as the mechanical properties and electrochemical corrosion behavior of Al/Sn–9Zn–xNi/Cu solder joints, were investigated. The microstructure of Sn–9Zn–xNi revealed that tiny Zn and coarsened Ni_5Zn_{21} phases dispersed in the β-Sn matrix. The wettability of Sn–9Zn–xNi solders on Al substrate was much better than that on Cu substrate. With increasing Ni content, the wettability on Cu substrate was slightly improved but became worse on Al substrate. In the Al/Sn–9Zn–xNi/Cu joints, an $Al_{4.2}Cu_{3.2}Zn_{0.7}$ intermetallic compound (IMC) layer formed at the Sn–9Zn–xNi/Cu interfaces, while an Al–Zn–Sn solid solution layer formed at the Sn–9Zn–xNi/Al interface. The mixed compounds of Ni_3Sn_4 and Al_3Ni dispersed in the solder matrix and coarsened with increasing Ni content, thus leading to a reduction in shear strength of the Al/Sn–9Zn–xNi/Cu joints. Al particles were segregated at both interfaces in the solder joints. The corrosion potentials of Sn–9Zn–xNi solders continuously increased with increasing Ni content. The Al/Sn–9Zn–0.25Ni/Cu joint was found to have the best electrochemical corrosion resistance in 5% NaCl solution.

KEY WORDS: Al–Cu dissimilar-metal solder joint; Sn–9Zn–xNi; Microstructure; Mechanical properties; Electrochemical corrosion; Corrosion potential

1. Introduction

Owing to its excellent electrical and thermal conductivities, high corrosion resistance and good plastic processing, copper is widely used in the manufacture of refrigerators, air conditioners, cables, central processing unit (CPU) radiators, *etc.* However, the huge consumption of Cu in industry had pushed up the price of Cu in recent years and thus low cost substitutes are highly sought after. Due to its lower cost, lower density, and similar electrical and thermal conductivities compared with Cu, Al is one of the promising substitutes for Cu, not only to reduce the cost, but also to take advantage of the properties of Al. Furthermore, it is necessary to join Cu with Al during manufacturing of items such as refrigerators and air conditioners, since Cu in some parts, such as the dry filter and compressor in a refrigerator, cannot be replaced by Al.

However, there are still many concerns about joining Al and Cu. Firstly, Al is very chemically active; it can easily form an oxide film on the surface, which could prevent joining. Secondly, brittle Al–Cu intermetallic compounds (IMCs) formed in the process of joining can significantly affect the mechanical properties of the joint[1]. Thirdly, the large difference in electrode potential between Al and Cu is expected to accelerate the electrochemical corrosion of the Al/Cu dissimilar-metal joints.

The joining methods, such as friction stir welding[2,3] and vacuum diffusion welding[4], have been applied to join Al and Cu, especially for straight pipes and tubes. There are, however, a large number of tiny, non-straight pipes and tubes in the manufacturing of refrigerators and air conditioners, and

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the production rate becomes a concern if friction stir welding and vacuum diffusion welding are applied.

Low-temperature soldering to join Al and Cu with lead-free solders can avoid the above problems, and is expected to provide convenient and reliable interconnections in the assembly of air conditioners. Since Sn cannot form IMCs with Al, it is necessary to add the elements that will form IMCs or provide a solid solution in Al, in order to obtain a reliable lead-free solder joint. Huang *et al.*[5] studied soldering Cu and Al with Sn–9Zn–xAg solder. It was found that the Al substrate would dissolve in the Sn–Zn based solder during soldering since the mutual solubilities between Zn and Al are large, and the Sn–Zn–Al solid solution would form at the Sn–9Zn/Al interface. It was claimed in previous studies that the addition of Ni[6], Bi[7] and Ga[8] elements to Sn–Zn based solder alloy would improve the wetting properties of the solders on Cu substrate.

The objective of the present work is to examine the effect of Ni content on the wettability of Sn–9Zn–xNi solders on Al and Cu substrates, as well as the interfacial microstructure, shear strength, and electrochemical corrosion behavior of the Al/Sn–9Zn–xNi/Cu joints, and to optimize the composition of Sn–9Zn–xNi solder in the Al/solder/Cu joints.

2. Experimental

Sn–9Zn–xNi (x=0, 0.1, 0.25, 0.5, 1, in wt%) solders were used for soldering Al and Cu in this work. Appropriate amounts of Sn (99.99 wt%), Zn (99.995 wt%) and Ni (99.9 wt%) were put into quartz tubes, and then the quartz tubes were evacuated and sealed. The mixture was melted at 500 °C for 3 h in a furnace, followed by cooling in water to form the required solder alloy. Cu (Type: TP2) and Al (Type: 3003) were used as the substrates for the solder joints. Harris-Aluminum solder 500 (Al-500) flux was used in the experiment.

The melting behavior of the solder was evaluated using a differential scanning calorimeter (DSC) in N_2 atmosphere. The specimens for the DSC tests were about 10 mg. The temperature range was from 50 to 350 °C, and the heating rate was 10 °C·min^{-1}.

The Sn–9Zn–xNi solder ingots were cut into small pieces of 4 mg in weight, and then melted in a specific device to form solder balls (1 mm in diameter). Al and Cu substrates were prepared with dimensions of 20 mm×20 mm×1 mm. Both substrates were treated with 10% NaOH and then 50% HNO_3 solutions to remove surface oxidates and other impurities, and finally cleaned ultrasonically in deionized water and alcohol. The solder balls were placed on the substrates covered with the flux, and then reflowed in a reflow oven for soldering, according to the temperature profile shown in Fig. 1. Wetting tests were conducted for five times to obtain the average result. Each wetting area of the solder ball on the substrates was calculated

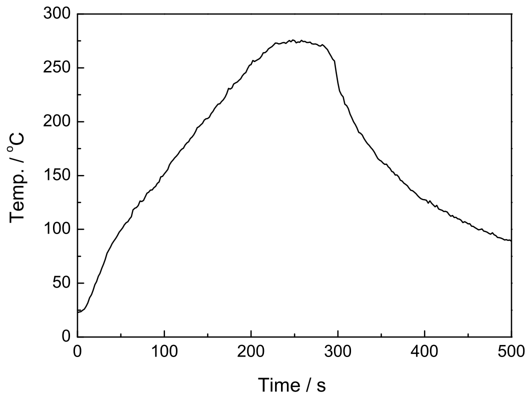

Fig. 1 Reflow curve for the soldering process

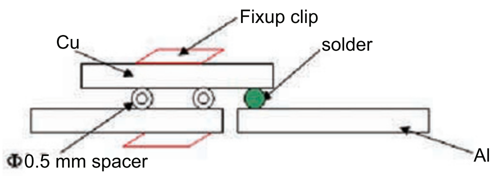

Fig. 2 Configuration of the Al/Sn–9Zn–xNi/Cu joint

using the Auto CAD software.

Fig. 2 shows the configuration of the Al/Sn–Zn–xNi/Cu joints. The solder balls were 50 mg in weight and about 2.35 mm in diameter. The Al and Cu substrates had dimensions of 60 mm×10 mm×1 mm, and the thickness of the solder between the two substrates was 0.5 mm. Shear tests of the solder joints were carried out using a hydraulic servo system (Shimadzu, Japan) at a shear speed of 0.3 mm·min^{-1}, corresponding to a shear strain rate of 10^{-2} s^{-1}. The microstructure of solder joints was observed by scanning electron microscopy (SEM, JEM-5600LV, Japan) and analyzed by energy dispersive X-ray detector (EDX, Lin KIS6587, England) and electron probe microanalyzer (EPMA, EPMA-1600, Japan).

A potentiodynamic polarization study was carried out in a triangular flask containing 5% NaCl solution at room temperature. The reference electrode for the electrochemical potential measurement was a saturated calomel electrode. Using insulating resin, the unwanted surface area was masked out, leaving with 25 mm^2 for the working electrode. Potential scanning was performed in the anodic direction from −1 to +0.5 V at a scan rate of 0.5 mV·s^{-1} using a CS300 electrochemical workstation. The corrosion behavior of solder joints were assessed by salt solution immersion test. The solders joints were immersed in 5% NaCl solution at 25±2 °C for 12 h and then the strength of solder joints after corrosion were conducted.

3. Results and Discussion

3.1 Microstructure of bulk Sn–Zn–xNi *solders*

Fig. 3 shows the backscattered electron images of