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Investigation of microstructure and properties near the interface of copper/aluminum brazed joint

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Abstract

Brazing of copper to aluminum using Al-Si alloy has been carried out in a resistance furnace. Microstructure and properties for Cu/Al brazing joint were studied by metallography, scanning electron microscope (SEM) and INCA energy disperse spectroscopy. Experimental results obtained showed that a reliable joint could be formed with the technology parameters: brazing temperature $T = 610–625\,^{\circ}C$, holding time $t = 2–3$ min and pressure $P = 0.4–0.8$ MPa. An obvious transition layer of intermetallic (IMC) with a thickness about 10 µm was formed near the interface of copper and the brazing alloy. Eutectic phase α(Al)-$CuAl_2$ and needle-like precipitates (AlCuSi phase) were found in the brazing seam region. Furthermore, an external pressure was helpful to the brazing progress, however, microhardness in the brazing seam region was too high with a big external pressure. A peak point of microhardness was found at the interface of Cu/Al brazing joint, and the transition layer of IMC phases became the initiation and propagation channel of micro cracks.

K e y w o r d s: Al/Cu joint, interface, microstructure, microhardness, cracks

1. Introduction

The complicated component manufactured with copper and aluminum dissimilar metals was widely used in the field of aerospace, chemical, electricity and refrigeration industry [1–3]. However, in thermophysical properties of copper and aluminum dissimilar metals such as melting point and thermal expansion coefficient existed huge differences, moreover, brittle intermetallic compounds (IMC) of copper and aluminum easily generated at elevated temperature, therefore fusion welding methods were very difficult to realize the connection of copper to aluminum dissimilar metals [4–6]. The method adopted for joining of copper and aluminum usually involved pressure welding and brazing. Direct brazing method has merits of low cost, simple process, so it can be used for large-area combining of copper and aluminum plates and manufacturing of composite plates of copper and aluminum with well integrated performance. Therefore, to resolve the existed problem relating to the direct brazing of copper and aluminum dissimilar metals was promising [1, 7–10].

In this issue, the reliable joint of copper and aluminum used in the power connector was manufactured by direct brazing method. Furthermore, the microstructure, metallurgical reaction and micro performance were analyzed by the means of optical microscope, scanning electron microscope (SEM), microhardness tester and energy spectrum analysis (EDS), for the interface of brazed joint of copper and aluminum dissimilar metals. All the research provided a favorable basis for establishing brazing process and choice of suitable brazing alloy for joining copper to aluminum. What's more, the present study was of practical significance for large-area combining of copper and aluminum and improving the application range of the composite components.

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Table 1. Chemical composition and thermal-physical properties of experimental materials

Materials	Chemical composition (wt.%)												
	Al	Cu	Zn	Pb	Mg	Ti	Fe	V	Bi	Mn	S	O	Si
Al (1035)	99.35	0.10	0.10	–	0.05	0.03	0.6	0.05	–	0.05	–	–	0.35
Cu (C11000)	–	99.0	–	0.005	–	–	–	–	0.002	–	0.005	0.06	–

Thermal-physical properties

	Melting point (℃)	Density ($g\,cm^{-3}$)	Specific heat volume ($J\,kg^{-1}\,K^{-1}$)	Heat conductivity ($W\,m^{-1}\,K^{-1}$)	Young's modulus (GPa)	Poisson ratio	Tensile strength (MPa)	Yield strength (MPa)	Brinell hardnesss, HB
Al (1035)	660	2.71	946	226	71	0.33	140	100	32
Cu (C11000)	1083	8.9	385	390	108.5	0.35	215	–	35–45

2. Experimental

Materials used in the test were Al (1035) and Cu (T2). Al-Si eutectic brazing alloy was adopted for the brazing process. Chemical compositions and thermal-physical properties of experimental materials were shown in Table 1. The Cu sample was machined into dimensions of $50 \times 50 \times 2$ mm^3 and Al sample into $50 \times 50 \times 3$ mm^3. Then the oxidation film and greasy dirt on surface of the base metal and brazing alloy were strictly eliminated by series of mechanical and chemical methods before brazing. The Al-Si brazing alloy was prepared into flaky material, with a thickness of about 1 mm. Finally, the test plates were assembled by sequence of Cu, Al-Si brazing alloy and Al to be brazed with the brazing flux HF-202. The process parameters of brazing were: heating rate 14–16 ℃ min^{-1}, brazing temperature 610–625 ℃, holding time 2–3 min and pressure on the base material surface 0.4–0.8 MPa.

The Cu/Al brazed samples were cut from the joint using electro discharge machining, then ground using different grades of sand paper, polished and finally etched with aqueous solution including 10 g pure NaOH and 60 ml H_2O. Optical metallographic examinations were carried out to characterize the microstructure across the interface of Cu/Al brazed joint. The microhardness distribution, elements distribution and compositions near the interface were measured by means of MH-5 microhardness microsclerometer and EDS, respectively.

3. Results and analysis

3.1. Microstructure feature of Cu/Al brazing

Microstructure feature in the interface of Cu/Al brazed joint was observed via metallographic microscope and JXA-840 SEM. The interface of metallurgical reaction formed between Al-Si brazing alloy and Al base metal was good. While copper and aluminum were brazed with Al-Si brazing alloy, the key problem remained was related to metallurgical reaction in the interface of Cu base metal and the brazing alloy. Referring to binary alloy phase diagram of Cu-Al [11], series of IMC of Cu and Al were easy to be formed, otherwise a phase of solid solution occurred. The IMC phase formed was hard and brittle, and it would seriously degrade the mechanical properties of the composite joint, when the thickness exceeded a certain value. The microstructure and the brazing section are shown in Fig. 1. It can be seen that three obvious regions included the transition region on Cu side, the middle brazing seam region and the transition region on Al side were formed in interface zone of the brazed joint. After the brazing process, the base metals remained in original shape, no serious corrosion occurred. Moreover, the interface of the joint combined well, without holes or other forming defects being found. A clear transition layer was formed related to the metallurgy reaction between Cu and Al-Si brazing alloy.

Micro phase was well-distributed in the brazing seam region, and lots of eutectic phase and needle-like precipitates were found (Fig. 2). Furthermore, the eutectic phase was confirmed to be α(Al)-$CuAl_2$, while the needle-like precipitates were mainly in AlCuSi phase, via the means of energy spectrum analysis. The needle-like precipitates existed near the interface of the Cu side and obvious aggregation was not observed, so it impacted less on the performance of the brazed joint.

3.2. Elements distribution near the interface of Cu/Al brazing

Elements transition plays an important role in the brazing metallurgy reaction. The elements distribution near the interface of Cu/Al brazing joint

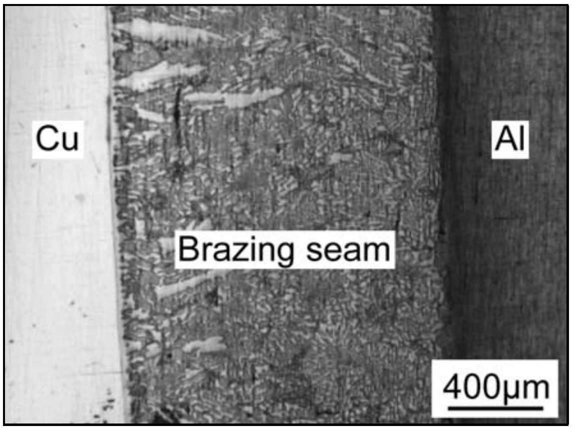

Fig. 1. Cross section of the Cu/Al brazing joint.

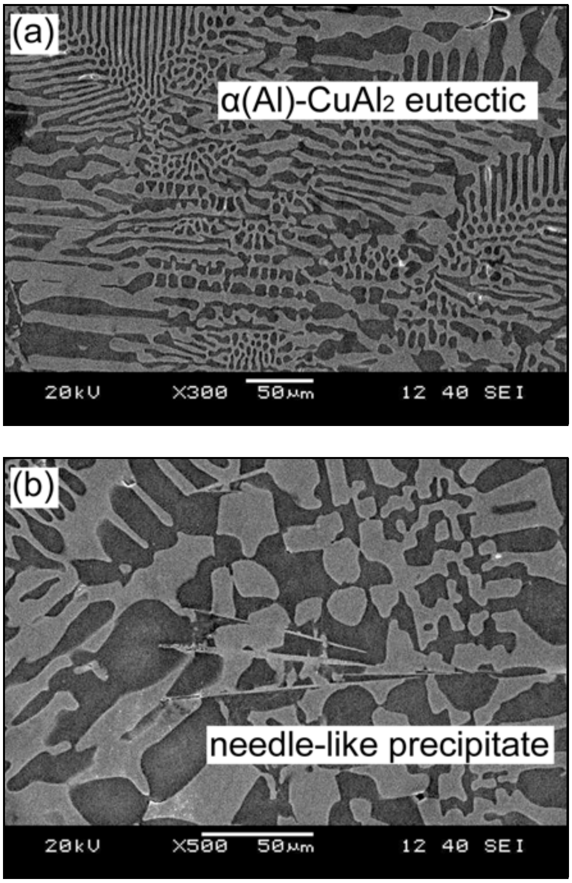

Fig. 2. Microstructure in the brazing seam region: a) α(Al)--$CuAl_2$ eutectic phase, b) needle-like precipitates.

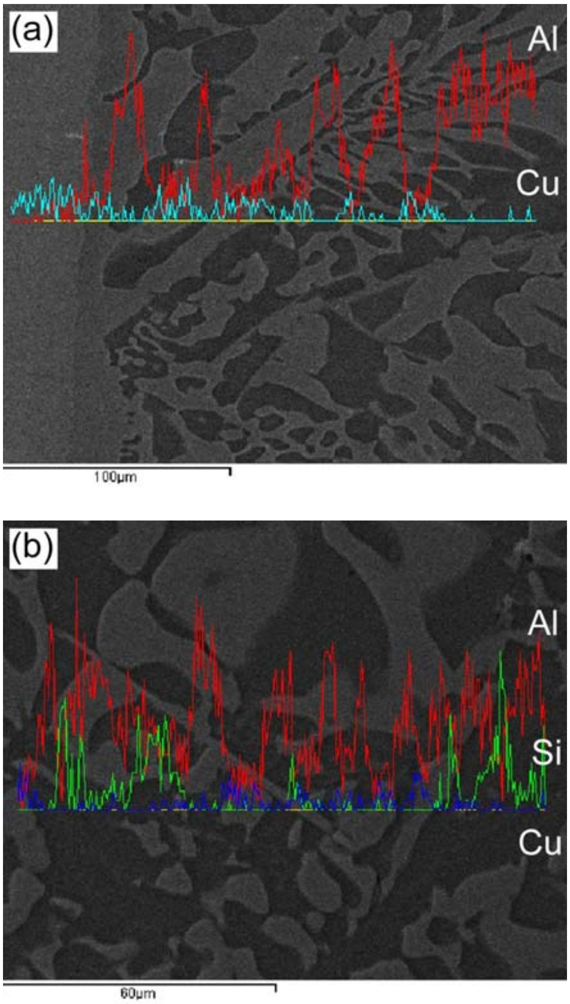

Fig. 3. Typical elements distribution in the Cu/Al brazing joint: a) elements distribution near the interface of Cu and the brazing seam region, b) elements distribution in the center of the brazing seam.

was analyzed by INCA energy dispersive spectroscopy. The elements distribution near the Cu side is shown in Fig. 3a. High proportion of Cu and Al was observed in the transition region, formed IMC layer of Cu-Al alloy. The performance of the brazed joint was closely related to the thickness of the IMC phase. The brazed Cu/Al joint with smaller thickness of IMC layer performed better. Elemental analysis results of A point showed that the elemental composition was Al: 64.71 %, Cu: 35.29 %. In other words, the phase in A point was $CuAl_2$. The grey phase, shown in Fig. 3a, was α(Al) solid solution. It can be seen that lots of Cu elements transited into the brazing seam region and formed eutectic phase.

Furthermore, the element distribution in the brazing seam region was measured by elements line-scanning, shown in Fig. 3b. IMC phases of Cu-Al alloy dispersed in the brazing seam region and no flake IMC phase was found, so the mechanical performance would not be degraded seriously. Si element was an important ingredient contained in the brazing alloy. After brazing, Si segregation existed in local area of the brazing seam region and a very small amount of Si primary crystal was observed.

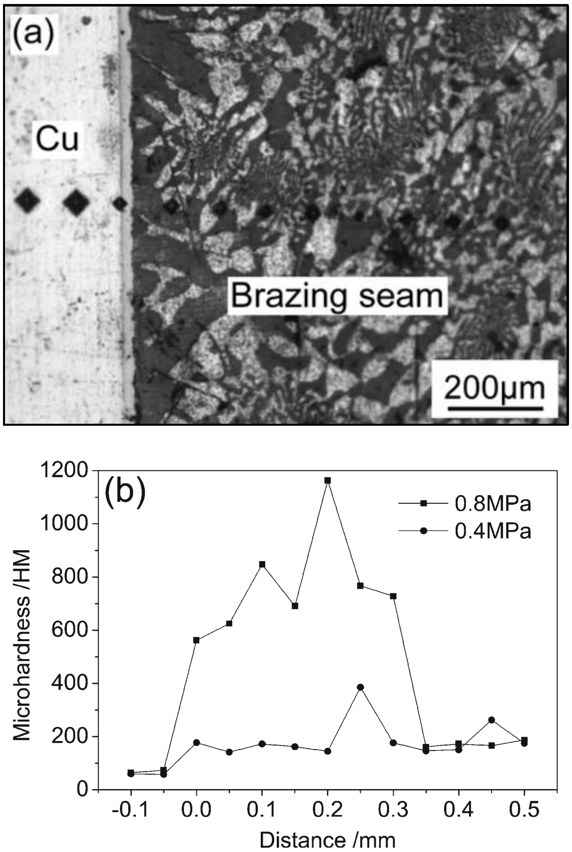

Fig. 4. Microhardness near the interface of Cu and the brazing seam region: a) testing location, b) microhardness profile.

3.3. Microhardness features near the joint

The microhardness near the interface of Cu/Al brazing joint was measured and the results are shown in Fig. 4. The test instrument and parameters were: the MH-5 type microsclerometer, 25 gf loading and a load time of 10 s. Different microhardness distribution in the Cu/Al joint was induced via the metallurgy reaction, which was influenced by the extra pressure applied on the surface of the joint. While the pressure changed in the brazing process, the microhardness feature of phases would be changed. The microhardness curves with different pressure are shown in Fig. 4b.

The microhardness of the Cu base metal was in the range of 55–63 MPa. Due to the formation of brittle phases, the microhardness in the brazing seam region changed obviously, 200–300 MPa, with the extra pressure 0.4 MPa. When the extra pressure elevated to 0.8 MPa, the microhardness in the brazing seam region increased noticeably. The microhardness in local area of the brazing seam region exceeded 800 MPa as shown in Fig. 4b, which indicated that a lot of IMC phases formed in this region. The pressure applied on parts to be joined in the brazing process was helpful to the spreading of brazing alloy and ejecting impurities, to obtain a sound joint without holes and pores.

However, in the case the extra pressure was too high, the base metals contacted with the brazing alloy too closely and an amount of the IMC phases increased. Thermal-physical properties of the IMC phases and the base metals were different, easily inducing stress concentration, so the performance of the brazing joint was reduced heavily.

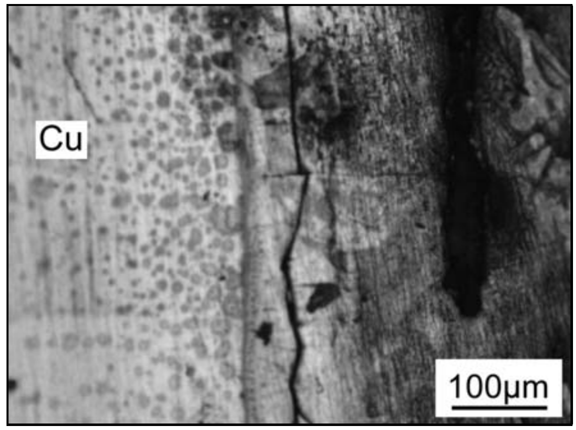

Fig. 5. Micro crack in the transition region at the Cu side.

3.4. Micro-crack in the interface of Cu/Al joint

The brittle IMC phase formed in the interface of Cu/Al joint induced stress concentration easily, playing an important role in the micro cracks origin and expansion in the joint, as shown in Fig. 5. Micro cracks were detrimental to the service performance of the brazed joint. Micro cracks emerged in the IMC layer of $CuAl_2$ phase, and extended along the interface of the IMC layer. The IMC layer distributed throughout the whole Cu/Al interface, therefore micro cracks existence in the IMC layer was fatal. Once this type of micro cracks emerged in the IMC layer, a fracture of the whole joint would easily occur. Therefore, the growth of intermetallic compounds of Cu-Al alloy in the interface should be strictly controlled via adjusting the process parameter of brazing temperature, holding time and the external pressure.

4. Conclusions

1. Under the process parameters of brazing temperature 610–625 ℃, holding time 2–3 min and external pressure 0.4–0.8 MPa, copper and aluminum dissimilar metals were brazed with Al-Si brazing filler alloy. A large number of eutectic phase α(Al)-$CuAl_2$ and dispersed needle-like precipitation were found in the brazing seam region.

2. Elements analysis revealed that the transition layer of IMC phase, about 10 µm, was formed at the interface of Cu base metal and the brazing alloy. Lots of Cu elements transited into the brazing seam region, Si segregation existed in local area and a small amount of Si primary crystal was observed.

3. Microhardness peak distributed near the interface of Cu base metal due to the formation of intermetallic compounds of Cu-Al alloys. While brazing, an extended pressure applied on parts to be jointed was helpful to improve the metallurgy reaction. However, a too high external pressure would lead to high microhardness due to the formation of IMC phase. Micro cracks usually emerged in the IMC layers and extended along the interface of IMC layer. So the growth of IMC layer should be restricted by controlling the heating temperature, holding time and external pressure to assure the combined performance of the obtained joint.

Acknowledgements

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