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Ultrasonic Brazing of Alumina to Copper Using Zn–Al Filler†

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Abstract

Ultrasonic brazing was applied to join alumina to copper using Zn-Al filler metals containing Al content up to 15 mass%. The intensity of ultrasound was 1 kW and 18 kHz. The joining mechanism was investigated by measuring the joining strength and analyzing the microstructure at interface of the joint.

First, Al_2O_3 was metallized by applying ultrasound in Zn-Al filler bath. Then, the metallized Al_2O_3 was brazed with Cu using the same Zn-Al fillers. The increase in application time of ultrasound and metallizing temperature raises the joinig strength of Al_2O_3/Zn-Al/Cu joint. The joining strength of Al_2O_3/Cu joint exhibits the maximum at Al content of 5 mass% in Zn-Al filler, and lowers with further addition of Al content.

The application of ultrasound during brazing accelerates the removal of bubbles and the reaction at the interface between alumina and filler metal. This gives rise to wetting of Zn-Al filler against alumina, and increasing the joinig strength of Al_2O_3/Cu joint.

KEY WORDS: (Ceramic-Metal Joining) (Ceramics) (Alumina) (Copper) (Ultrasonic Brazing) (Joining) (Brazing) (Zinc) (Aluminum) (Filler Metals)

1. Introduction

Joining of ceramics to metals has received considerable interests in recent years in connection with related fields of application of ceramics. The brazing methods of ceramics to metals are divided into the heat-resistant metals method[1], active filler metals method[2], molten aluminum method[3–5], oxide utilizing method[6,7]. The thermal stress in ceramic/metal joint arises from the difference of thermal expansion coefficient between ceramic and metal after joining. Soft metals which are inserted between ceramics and metals are often used to relax the thermal stress in joints. Although the decrease in joining temperature also reduces the thermal stress in ceramic/metal joints, the wettability of brazing fillers is simultaneously impared. Nomaki *et al.*[8] have reported the ultrasonic soldering of glass and ceramics using Pb-Sn solder. There has been only a little studies of ultrasonic effect on brazing ceramic to metal using other fillers.

This work tries to improve the brazeability of Zn-Al filler metals during joining of alumina to copper by applying the ultrasound.

2. Experimental

Materials used were 99.62 mass% Al_2O_3 containing 0.1 mass%SiO_2 and others and tough pitch copper containing 0.03 mass% O. The size of materials was 6 mm in diameter and 4 mm in thickness. Table 1 gives a series of composition for Zn-Al filler metals containing Al content up to 15 mass%. **Figure 1** shows the phase diagram[9] of the Zn-Al filler metals. **Figure 2** shows the process of ultrasonic brazing of ceramics to metal in Zn-Al filler bath. Alumina were first metallized by applying the ultrasound in Zn-Al filler bath. The intensity of ultrasound was 1 kW

Table 1 Chemical composition of Zn-Al alloys used.

Zn-Al	Al (mass %)	Liquidus temperature (K)
Zn		692
Zn - 5Al	5	655
Zn -10Al	10	703
Zn -15Al	15	728

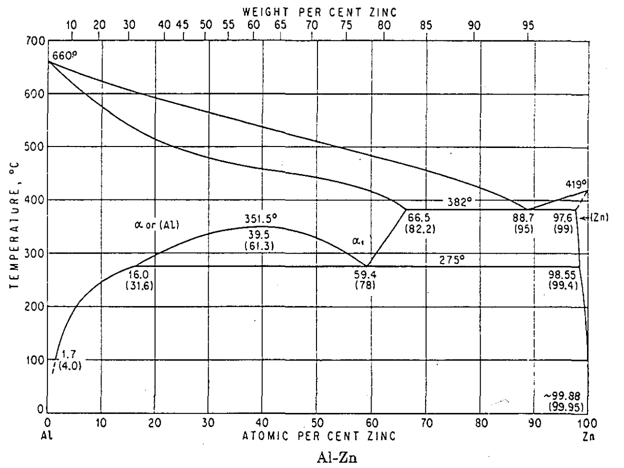

Fig. 1 Phase diagram of Zn-Al binary alloys.

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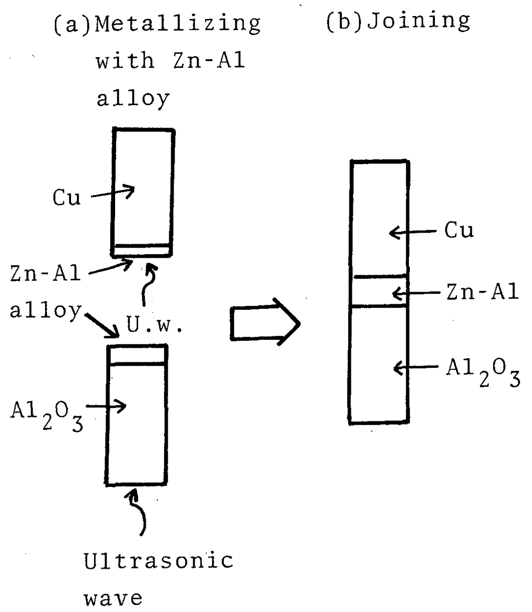

Fig. 2 Process of ultrasonic brazing of ceramics to metal.

and 18 kHz. The brazing temperature and applying time of ultrasound were 673 to 773K and 0 to 90s, respectively. After metallizing alumina, alumina was lapped with copper which was coated with the same filler metal by applying the ultrasound in 3 s.

The joining strength of Al_2O_3/Cu joints brazed with Zn-Al filler was evaluated by fracture shear loading using a cross head speed of 1.67×10^{-2} mm/s, and the microstructure was analysed by scanning electron microscopy and EDX microanalysis.

3. Results and Discussion

3.1 Joining strength of Al_2O_3/Cu joint formed by ultrasonic brazing

Figure 3 shows the change in joining strength of Al_2O_3/Zn-5Al/Cu joint with application time of ultrasound. The application of ultrasound during brazing improves the strength of Al_2O_3/Cu joint at all joining temperatures. For instance, the strength of the joint increases up to 45 MPa at 90s with increasing the application time of ultraound at joinig temperature of 723K, although the joint without applying ultrasound doesn't be joined soundly.

The ultrasonic wave accelartes the motion of molten alloys in the filler bath and removes bubbles at the almina-filler interface. Thus, the ultrasound improves the wetting of alloys against alumina. This results in the improvement of joining strength of Al_2O_3/Cu joints.

The increase in joining temperature raises the joining strength at a constant applying time of ultrasound. **Figure 4** represents the change in joining strength of Al_2O_3/Cu joint using Zn-5Al filler with joining temperature at the

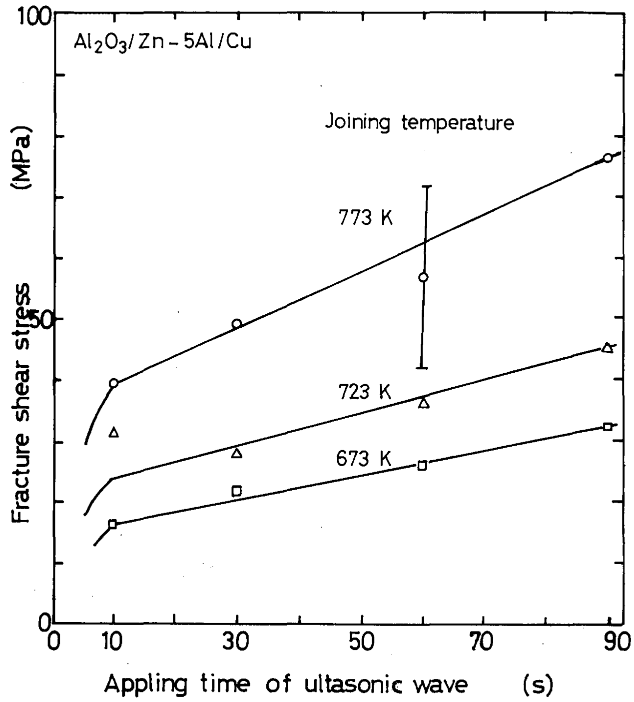

Fig. 3 Change in joining strength of Al_2O_3/Cu joint using Zn-5Al filler with application time of ultrasound.

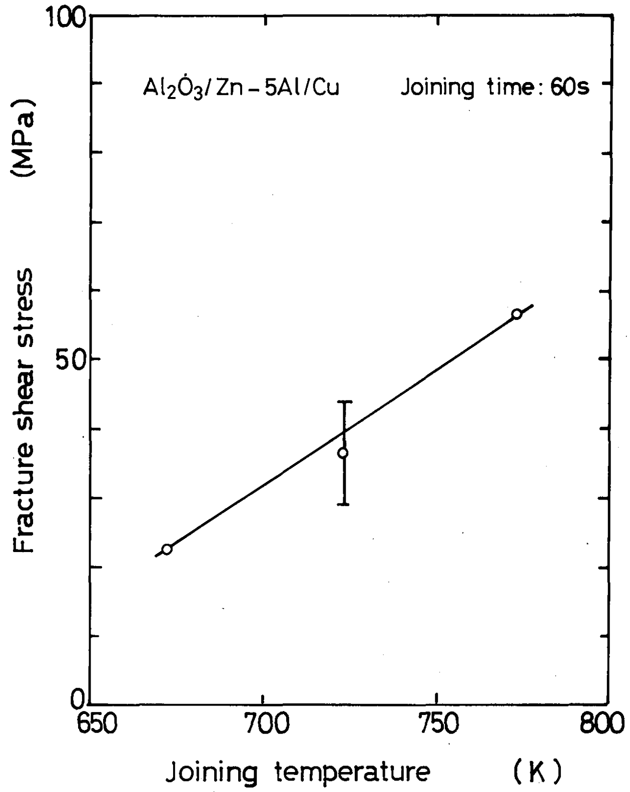

Fig. 4 Change in strength of Al_2O_3/Cu joint using Zn-5Al filler with joining temperature at application time of 60s.

constant applying time of 60s. The strength of joint changes from 21 MPa at 673K to 54MPa at 773K at brazing condition of 60s.

The change in joining strength of Al_2O_3/Cu joint with

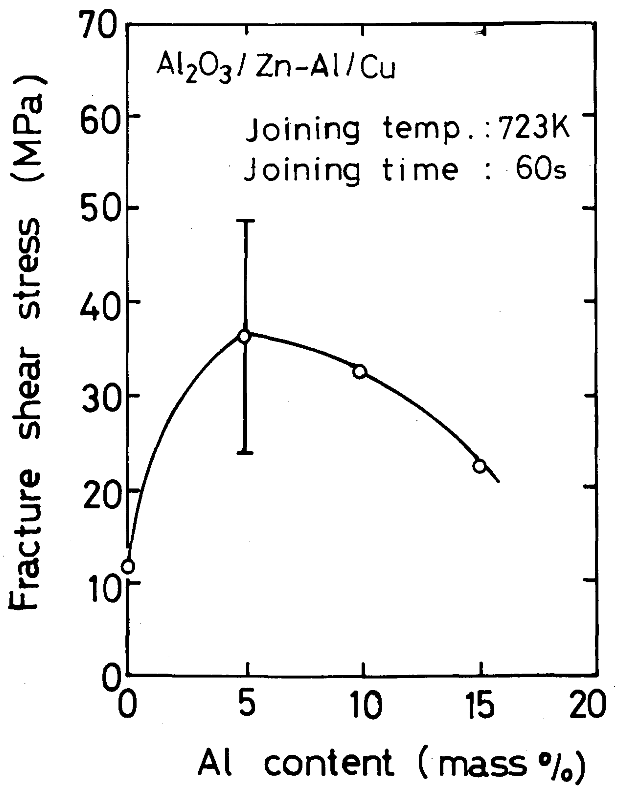

Fig. 5 Change in joining strength of Al_2O_3/Cu joint with Al content in Zn-Al filler at joining condition of 723 K and 60 s.

Al content in Zn-Al filler at joining condition of 723K and 60s. is shown in **Fig. 5**. The joining strength of Al_2O_3/Cu joint increases with increasing Al content in the filler from 12 MPa at 0 mass% Al, and exhibits the maximum value of 35 MPa at 5 mass%Al. With further adding Al content, the strength lowers to 25 MPa at 15 mass% Al through the maximum value.

The increase in joining strength of Al_2O_3/Cu joint is two factors. First, the wetting of molten Zn-Al filler against Al_2O_3 is improved by an addition of aluminum in the initial stage up to Al content of 5 mass%. MacDonald[3] and Naka *et al.*[10] have indicated that the molten aluminum definitely wets Al_2O_3. The aluminum in Zn-Al filler dissolves or reacts with Al_2O_3. This leads to accelerate the wetting of the filler against Al_2O_3. Secondly, the mechanical properties of Zn-Al fillers are improved by mixing Al into Zn. This also raises the joining strength of Al_2O_3/Cu joint.

However, the mixing of excess amounts of Al raises the viscosity of molten Zn-Al fillers. The ultrasonic wave can't be effectively applied to Al_2O_3 in such viscous molten fillers. Then, the high viscosity of the filler results in lowering the joining strength of Al_2O_3/Cu joint.

The fracture surface of Al_2O_3/Zn/Cu joint brazed at 723K for 60s is shown in **Fig. 6**. The fracture of the joint takes place at the interface between Al_2O_3 and Zn filler.

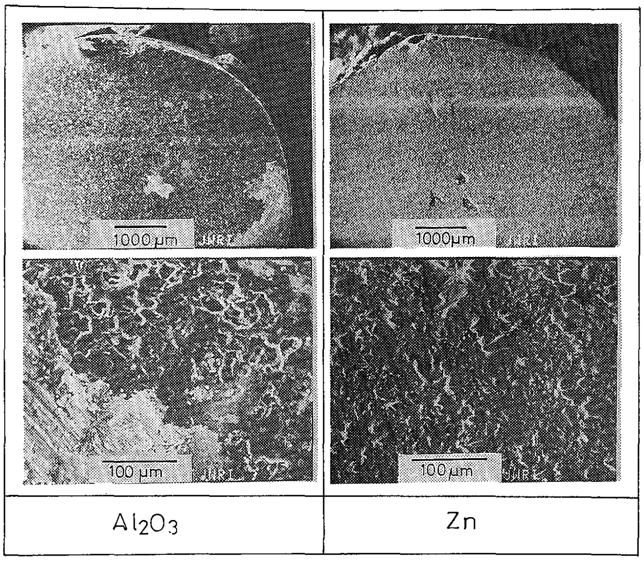

Fig. 6 Fracture surface of Al_2O_3/Zn/Cu joint brazed at 723 K for 60 s.

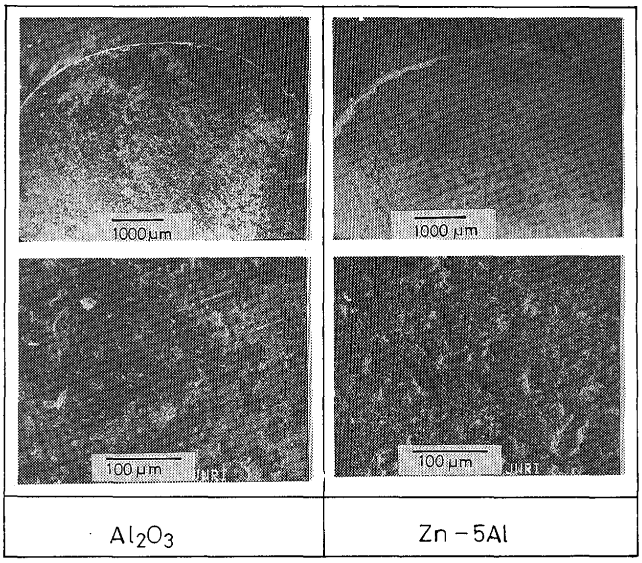

Fig. 7 Fracture surface of Al_2O_3/Zn-5Al/Cu joint brazed at 723 K for 60 s.

Small amounts of Zn which shows the ductile fracture feature adhesived on Al_2O_3. The fracture surface of Al_2O_3/Zn-5Al/Cu filler brazed at 723K for 60s is shown in **Fig. 7**. Compared with Al_2O_3/Zn/Cu joint, Al_2O_3/Zn-5Al/Cu joint exhibits the larger amounts of the filler adhesived on the fracture surface of Al_2O_3. Higher bonding strength between the filler and Al_2O_3 in Al_2O_3/Cu joint brazed with Zn-5Al filler is attributable to the larger parts of the filler on Al_2O_3, and results in the higher joining strength of the joint.

Figure 8 shows the joining strength of Al_2O_3/Cu joint using Zn or Zn-5Al filler brazed at 723K for 60s at testing temperatures from room temperature to 623K.

Al_2O_3/Cu joint with Zn filler maintains the joining strength up to 523K, though the joining strength rises a little with increasing testing temperature from room temperature. With further increasing testing temperature the joining strength of the joint lowers drastically.

Al_2O_3/Cu joint with Zn-5Al filler shows the larger temperature dependence of joining strength as shown in **Fig. 8**. The joining strength of the joint changes from 36.5MPa at room temperature to 18MPa at 623K. The joint withZn-5Al filler represents the higher values at all testing temperatures, compared with the joint with Zn filler.

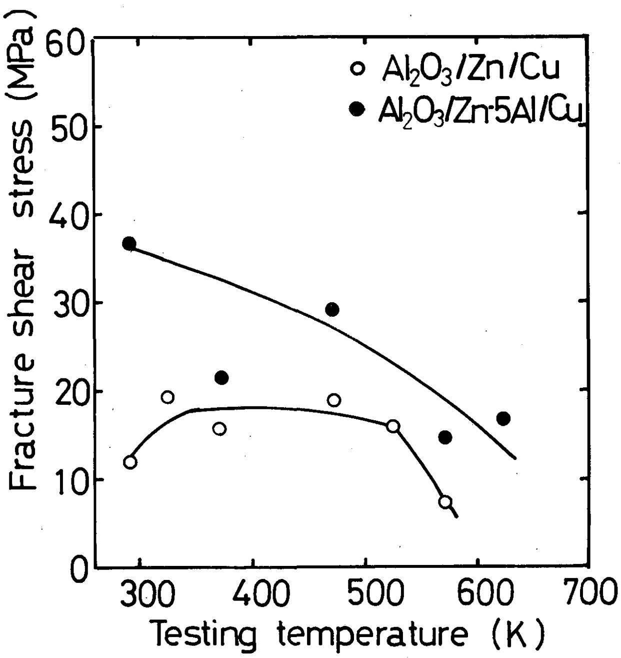

Fig. 8 Change in joining strength of Al_2O_3/Cu joint using Zn or Zn-5Al filler brazed at 723K for 60s with testing temperature.

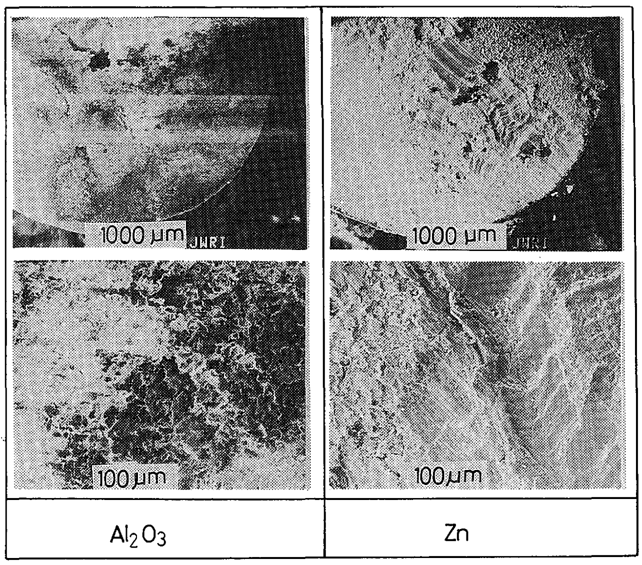

Fig. 9 Fracture surface of $Al_2O_3/Zn/Cu$ joint brazed at 1273K for 60s at testing temperature of 573K.

The fracture surfaces of Al_2O_3/Cu joints with Zn filler in **Fig. 9** and Zn-5Al filler in **Fig. 10** show the ductile fracture of the fillers at all testing temperatures. The fracture of Al_2O_3/Cu joint withZn or Zn-5Al filler takes place in the part of filler. These observations of fracture surface demonstrate that the decrease in strength of Zn or Zn-5Al fillers at high testing temperature is attributable to the decrease in the joining strength of Al_2O_3/Cu joints.

3.2 Joining microstructure at interface of Al_2O_3/Cu joint

Figure 11 shows the microstructure and EDX spot analyses of Al_2O_3/Cu joint with Zn filler brazed at 723K for 60s. Zinc filler well wets Al_2O_3, and no defects are observed at the interface between Al_2O_3 and filler. Cu-Zn

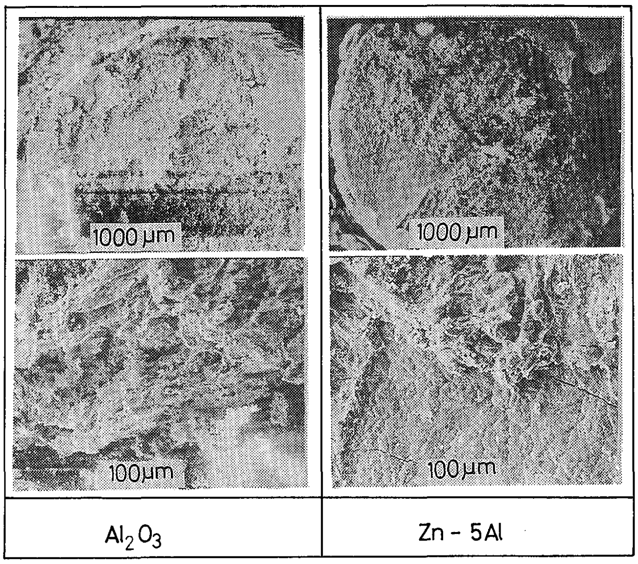

Fig. 10 Fracture surface of Al_2O_3/Zn-5Al/Cu joint brazed at 1273K for 60s at testing temperature of 623K.

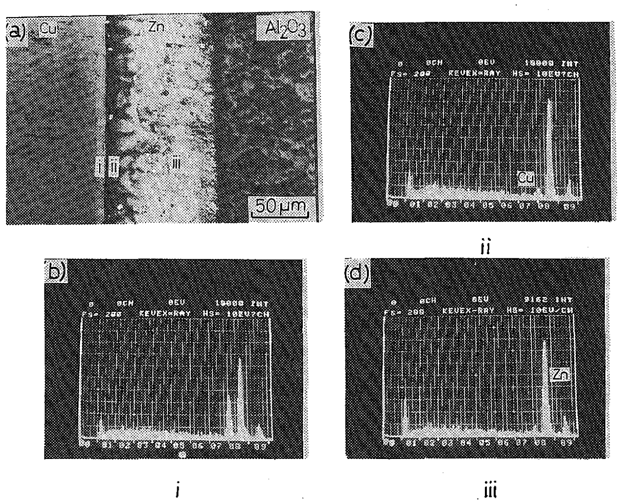

Fig. 11 Microstructure and EDX spot analyses of Al_2O_3/Cu joint with Zn filler brazed at 723K for 60s.

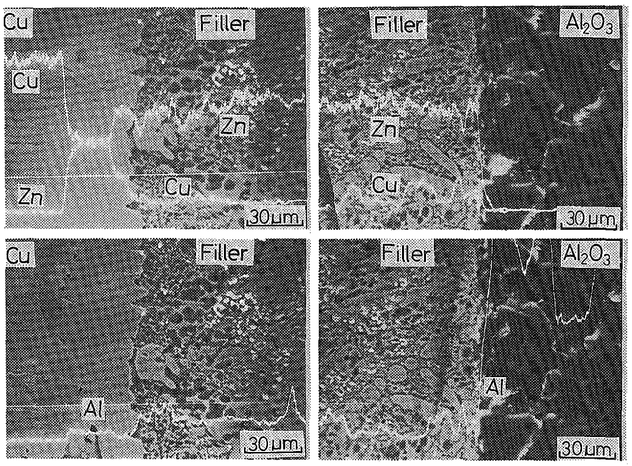

Fig. 12 Microstructure and line analyses of Zn, Cu and Al in Al_2O_3/Cu joint with Zn-Al filler brazed at 723K for 60s.

solid solution in Fig. 11(i) is formed at the interface between Cu and Zn filler. Only small amounts of Cu dissolve into Zn filler as shown in Figs. 11(ii) and (iii).

Figure 12 shows the microstructure and line analyses of Zn, Cu and Al in Al_2O_3/Cu joint with Zn-5Al filler brazed at 723K for 60s. The Zn-5Al filler definitely wets Al_2O_3. At the interface between Cu and Zn-5Al filler two intermediate phases of Cu-Zn system are formed. The second intermediate phase dissolves into the Zn-Al filler, and the matrix phases of Zn-Al filler are composed of Zn solid solution and Al solid solution.

4. Conclusion

The joining of Al_2O_3 to Cu with Zn-Al filler was conducted by ultrasonic brazing at 673–773K and 0–90s. The Zn-Al fillers contained Al content up to 15 mass%, and the intensity of ultrasound used was 1 kW and 18 kHz. The joining mechanism of the ultrasonic brazing was investigated by measuring the joint strength and observing the microstructure of the interface of the Al_2O_3/Cu joint.

The increase in applying time and brazing temperature raises the joining strength of Al_2O_3/Cu joint. The ultasonic wave activates the motion of molten alloys in the Zn-Al fillers, and accelarates the wetting of alloys of alloys against Al_2O_3. This leads to the increas in joining strength of the joint.

The addition of Al to Zn filler improves the wettability and mechanical properties of the filler against Al_2O_3. This results in the superior strength of Al_2O_3/Cu joint brazed with Zn-Al filler under applying the ultrasound.

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