Evaluation for Al/Cu bonding by liquefaction after solid phase diffusion in the air

Hiroshi Kawakami*, Jippei Suzuki*, Masanori Fujiwara**, Junya Nakajima** and Keiko Kimura**
*Faculty of Engineering, Mie University, **Graduate School of Mie University, Tsu, JAPAN

ABSTRACT The bonding for Aluminum and Copper in the air is investigated in this study. This bonding method does not include the special process of removing aluminum oxide films. In case of this bonding, each metal is heated at bonding temperature where is above eutectic temperature of Al-Cu system and below melting point of Aluminum. The liquefaction around the bonding surface occurs after the diffusion at solid state of each metal. This phenomenon is predicted by the temperature range above eutectic temperature of Al-Cu equilibrium phase diagram.

1. INTRODUCTION

Aluminum is needed as the base metal of some new products, because it has low density and electrical resistivity. However, Aluminum is known as the metal which is more difficult for bonding and welding than steel. One of reason is obstruction effect of the oxide films formed on the surface.

The simple Al/Cu bonding in the air is investigated in this study. This method includes the simple preprocessing and the heating over the eutectic temperature of Al-Cu system.

2. EXPERIMENTAL MEHOD

2.1 Specimen and preprocessing

The Round bars (the diameter of 6mm) of pure Aluminum and Copper are used as the specimen. These metals are standardized as A1070 and C1020 in JIS (Japanese Industrial Standard), respectively. Chemical compositions of them are shown as follows.

A1070: 0.04Si, 0.23Fe, 99.73Al
C1020: 99.9Cu

Each metal was cut 70mm in length by mechanical cutting. The bonding surface of each specimen was polished by polishing paper #2000. After polishing, the cleaning of surface was curried out by Acetone.

2.2 Experimental apparatus and process

Fig.1(a) shows the apparatus used in this experiment. The specimens were set in the jigs. The electrical resistance furnace heated the specimens. The furnace opens always on to the atmosphere. Uniform temperature distribution exists in the length of 30mm around the bonding surfaces. An alumel-chromel thermocouple (JIS K type) was fixed on Aluminum at 10mm from the bonding surface. The bonding temperature was controlled successively by the controller using the measurement results from the thermo-couple. The dead weight located the upper side of specimen and gives the bonding load. The concentration of oxygen around specimen was controlled by the flow quantity of nitrogen gas into the furnace.

The bonding temperature was selected in the temperature range over the eutectic temperature and below the melting point of Aluminum. The bonding load was added before the heating[1].

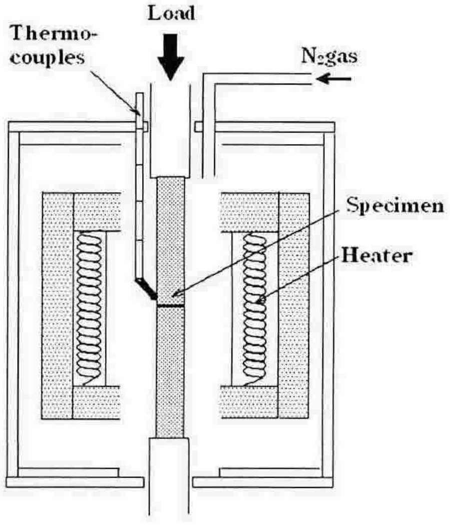

Fig.1 Apparatus of bonding.

3. EXPERIMENTAL RESULTS

3.1 Effect of bonding temperature

Fig.2 shows the results of the tensile load of the bonding specimens at initial bonding pressure of 0.70MPa. Effect of bonding temperature on tensile load is observed slightly. Maximum load at each heating temperature is obtained on the initial stage. The layer of brittle intermetallic compound and melted zone may be very narrow in initial stage. Tensile load of the bonded specimen becomes to be changeable with the increasing of bonding time. The melted zone increases by the additional diffusion and is removed successively. Increment of the heating temperature reduces the heating time for the achievement of bonding.

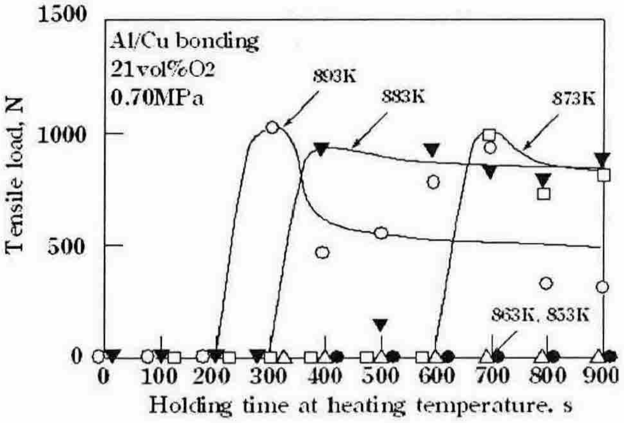

Fig.2 Effect of bonding temperature on tensile load of specimen.

3.2 Effect of bonding pressure

Diagram of the time conditions for the beginning of bonding is shown in Fig.3. The beginning time is evaluated by using the time need for tensile load of 500N below 700s.

The tetragon mark shows the result in the air. In case of initial bonding pressure of 0.35MPa, the bonding in the air is limited (Fig.3(a)). On the other hand, in case of 0.70MPa, the beginning of bonding was observed in the wide temperature range over 873K (Fig.3(b)). This result suggests that increasing of pressure improves the coherence of bonding surfaces.

3.3 Effect of oxygen concentration

The oxygen concentration during bonding process was controlled by the flow of nitrogen gas into electric furnace from start time of heating.

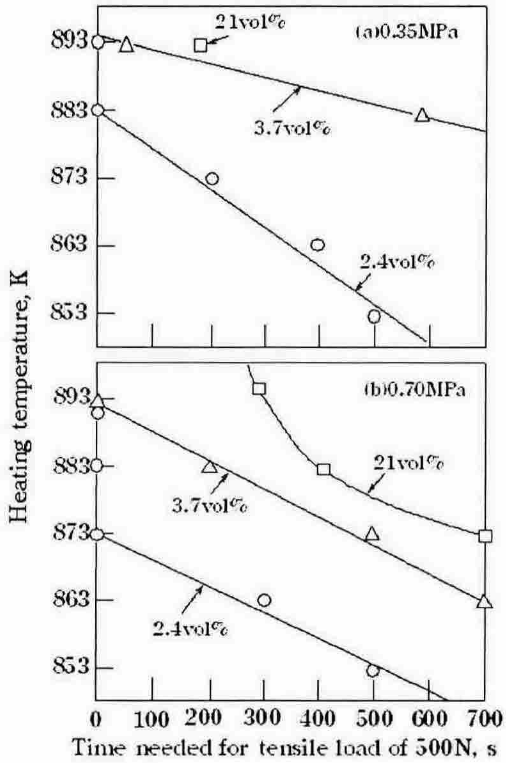

Fig.3 Effect of bonding pressure and oxygen concentration on beginning of bonding.

Decrement of oxygen concentration around the specimen decreases the temperature where the bonding can be carried out and reduces the bonding time (Fig.3(a) and (b)). This result suggests that oxygen concentration effect on the forming and the growth of oxide film on each bonding surface.

3.4 Observation of fracture surface

Fig.4 shows the appearance of fracture surface of copper-side specimen. The black and silver area are observed in the surface at short-time range of bonding (Fig.4(a)). Al, Cu and O were detected in black area by EPMA. On the other hand, Al and Cu were detected in silver area. At long-time range, the fracture surface becomes to be occupied by silver area as shown in Fig.4(b) and the liquefaction or the fusion around the bonding surface was observed by the appearance of specimen[2].

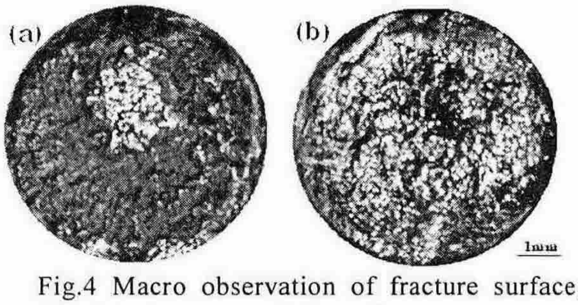

Fig.4 Macro observation of fracture surface; (a) shot-time range, (b)long-time range.

4. Evaluation for this bonding

4.1 Liquefaction time-temperature

The behavior of liquefaction occurred around the bonding surface was measured by the displacement and the appearance of specimen. Fig.5 shows the time-temperature range of liquefaction. The time of liquefaction becomes to be long with the decrement of bonding temperature. The liquefaction could not be observed at 813K.

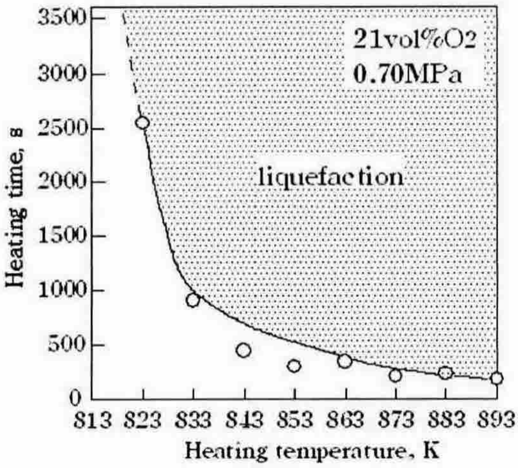

Fig.5 Time-temperature range of liquefaction.

4.2 Evaluation by phase diagram

Fig.4 and 5 shows that liquefaction around the bonding surface occurred after solid state diffusion. Equilibrium phase diagram is useful for most of bonding and welding processes. Al-side diagram of Al-Cu system is shown in Fig.6. The arrow in diagram indicates the progression of bonding process. When the solid state diffusion over eutectic temperature begins, the copper concentration in alpha phase becomes to increase. The liquefaction occurs around Al side of bonding surface, because Cu concentration exceed that of solidus as shown in Fig.6. Finally, increment of Cu concentration in this area (the hatching area of specimen in Fig.6) occurs isothermal solidification as theta phase. However, because of the characteristic shape of this joint, the end of liquefaction can not be controlled by the isothermal heating like TLP bonding[3].

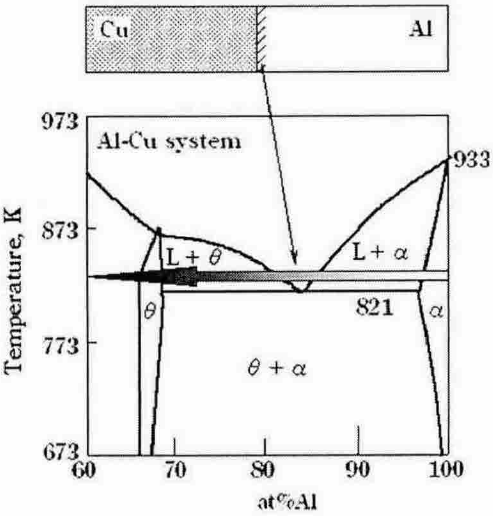

Fig.6 Bonding process presented in Al-Cu equilibrium phase diagram.

5. CONCLUSIONS

Dissimilar bonding of Aluminum and Copper in the air can be accomplished by this method. The bonding process is constituted the solid state diffusion and liquefaction. Al-Cu equilibrium phase diagram is useful to consider the phenomenon occurred in the bond.

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