Spot brazing of aluminum to copper with a cover plate

Junya Hayashi and Yasuyuki Miyazawa

Metallurgical Engineering (Materials Science), Tokai University,
4-1-1, Kitakaname, Hiratsuka-shi, Kanagawa-ken, 259-1292, Japan

E-mail: ymiyazawa@tokai-u.jp

Abstract. It is difficult to join dissimilar metals when an intermetallic compound is formed at the joining interface. Spot brazing can be accomplished in a short time by resistance heating. Therefore, it is said that the formation of an intermetallic compound can be prevented. In this study, aluminum and copper were joined by spot brazing with a cover plate. The cover plate was used to supply heat to base metals and prevent heat dissipation from the base metals. The ability to braze Al and Cu was investigated by observation and analysis. Pure aluminum (A1050) plate and oxygen-free copper (C1020) plate were used as base metals. Cu–Ni–Sn–P brazing filler was used as the brazing filler metal. SPCC was employed as cover plate. Brazing was done with a micro spot welder under an argon gas atmosphere. Brazing ability was estimated by tensile shear strength and cross sectional microstructure observation. Al and Cu can be joined by spot brazing with Cu-Ni-Sn-P brazing filler and cover plate.

1. Introduction
Joining of dissimilar metals is a very important technology for the manufacturing field [1]. However, it is difficult to join dissimilar metals when intermetallic compounds are formed at the joining interface. However, brazing is effective as a joining method for dissimilar metals. Therefore, many research results have been reported [2–8]. Spot brazing can be accomplished in a short time by resistance heating. Therefore, it is said that the formation of intermetallic compounds can be prevented.

Combinations of dissimilar metals largely depend on the intended use. Joining of Al and Cu is expected to be applied to cooling products for electronic devices. Specific resistance and heat conductivity are very important because spot brazing or spot welding is accomplished by a heat source using resistant heating. Al and Cu have low specific resistance and high heat conductivity. Therefore, it is difficult to ensure the heat amount required for brazing (welding). Studies using spot welding with a cover plate have been carried out to solve this problem [9–11]. Figure 1 shows a schematic diagram of spot brazing with a cover plate. The cover plate is used to supply heat to the base metals and prevent heat dissipation from the base metals. No such research on spot brazing with a cover plate has yet been reported.

In this study, Al and Cu were brazed by spot brazing using a cover plate. The ability to braze Al and Cu was investigated by observation and analysis.
2. Experimental procedure

2.1. Base metals, brazing filler metal and cover plate
Pure aluminum (A1050) plate (width 7 mm, length 50 mm, and thickness 0.8 mm) and oxygen-free copper (C1020) plate (width 7 mm, length 50 mm, and thickness 0.8 mm) were used as the base metals. Cu–Ni–Sn–P brazing filler (CuBal.Ni5.7Sn9.7P7: width 5 mm, length 5 mm, and thickness 20 μm) was employed as the brazing filler metal. The Cu–Ni–Sn–P brazing filler (MBF2005® Metglas®, Inc.) was produced by liquid quenching solidification. As a preliminary experimental result, Al–Cu joints brazed with Cu–Ni–Sn–P brazing filler have higher tensile shear strength than Al–Cu joints brazed with other filler metals. Therefore, Cu–Ni–Sn–P brazing filler was used in this study.

The cover plate was of suitable material with a high specific resistance and low heat conductivity. In this study, SPCC (cold-rolled steel sheet: width 7 mm, length 12 mm, and thickness 0.5 mm) was used as the cover plate.

Figure 2 shows a schematic diagram of the specimen. Figure 3 shows the outside appearance of the specimen.

2.2. Brazing condition
Brazing was done with a micro spot welder (Figure 4) in an argon gas atmosphere. Figure 5 shows a schematic diagram of the spot brazing process. Table 1 shows brazing conditions. Brazing currents were 700, 800, 900, 1000, and 1100 A at 3.5 V for 2 s under a 4-kgf as brazing load.

2.3. Microstructure observation and EPMA
After brazing, the outside appearance was examined. The specimen was then cut along the center line, and cross sections were polished using emery paper and a buffing cloth. Sodium hydroxide was used to etch the Al base metal side, and ferric chloride was used to etch the Cu side. After etching, the cross-sectional microstructure was examined by optical microscope. Furthermore elemental distributions at the brazed joint were analyzed by EPMA to investigate the interfacial reaction between the base metal and the molten brazing filler metal.

2.4. Tensile shear test
Tensile shear strength (fracture load) of the Al–Cu brazed joint was measured to estimate its mechanical properties. Tensile shear strength was measured by a tensile test machine (Instron® 3367) with a cross-head moving speed of 1 mm/min.
3. Results and Discussion

3.1. Effect of cover plate
Figure 6 shows tensile shear strength of the specimens brazed using and not using a cover plate. According to Figure 6, when the cover plate was used, the tensile shear strength was increased by approximately 40%.

Figure 7 shows typical cross-sectional microstructure of specimens brazed with and without using a cover plate. According to Figure 7, when the cover plate was used, the volume of the brazed layer was larger. The cover plate prevents heat dissipation from the base metals, thereby generating more heat. Furthermore, the cover plate became a heat source due to its low heat conductivity, and it supplied heat to the base metals. Therefore, it seems that the amount of heat at the brazed layer is increased, and an interface reaction occurred drastically. When the cover plate was set on the Al side or on both the Al and Cu sides, the Al side fully melted, and brazing was impossible. Therefore, the cover plate was set Cu side only.
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3.2. Microstructure observation

Figure 8 shows the relation between brazing current and the cross-sectional microstructure of the Al–Cu brazed joint with Cu–Ni–Sn–P brazing filler and a cover plate. According to Figure 8, the volume of the brazed layer increases with increased brazing current. It seems that the generated amount of heat increases with increasing brazing current. Also, the cover plate and Cu were joined above 800 A. The cover plate surface was sprayed with boron nitride solution to prevent joining of the cover plate to the Cu. However, the cover plate and Cu were still join. Furthermore, brazing filler metal did not melt at 700–1000 A. causing brazing filler metal foil to remain. However, brazing filler metal was fully melted at 1100 A.

Figure 9 shows typical cross sectional microstructure at the Al–Cu brazed joint. According to Figure 9, an interface reaction on the Al side occurred drastically. This seems to have been due to the difference between the melting points of Al and Cu. The brazed layer contained voids, but this was caused by polishing. Before polishing, a good void-free brazed layer was formed.
3.3. EPMA analysis

Figure 10 shows the elemental distributions by EPMA at the Al–Cu brazed joint with Cu–Ni–Sn–P brazing filler and a cover plate. As seen in Figure 10, the brazed layer mainly consists of an Al-rich layer and a Cu-rich layer. The Al-rich layer consists of Al solid solution, Al–P compound, and Cu3P or CuP2 compound by Al–P and Cu–P phase diagrams. The Cu-rich layer consists of Cu solid solution, Cu–Ni alloy phase, Cu3P or CuP2 compound, and Al–Cu compound by Cu–Ni and Cu–P phase diagrams. Nickel is detected in the Cu-rich layer. From phase diagrams, Ni–Al alloy phase is precipitated at the Cu-rich layer. Sn concentrates at the interface between the brazed layer and Cu base metal where Cu–Sn compound is formed. It seems that this compound has little effect on tensile shear strength. Phosphorus exists in the overall brazed layer.

![Figure 10](image)

**Figure 10.** The elemental distributions by EPMA at the Al–Cu brazed joint with Cu–Ni–Sn–P brazing filler and cover plate. Brazing current: 1100 A, brazing time: 2 s, brazing load: 4 kgf.

3.4. Tensile shear test

Figure 11 shows the relation between brazing current and tensile shear strength of the Al–Cu joints brazed with Cu–Ni–Sn–P brazing filler and cover plate. As seen in Figure 11, tensile shear strength increases with increasing brazing current. It seemed that the brazed joint area increases with increasing brazing current (Figure 8). Also, the volume of brazing filler metal foil decreases with increasing brazing current. When the brazing filler metal foil did not melted, the Al–Cu brazed joints have low tensile shear strength. However, when the brazing filler metal foil is melted, the Al–Cu brazed joints have high tensile shear strength.
In this study, Al and Cu were joined by spot brazing using a cover plate. The ability to braze Al and Cu was investigated by observation and analysis. The results are as follows:

(1) In when a cover plate was used, tensile shear strength was increased by approximately 40 percent.
(2) The volume of the brazed layer was increased with increasing brazing current. The generated amount of heat was increased with increasing brazing current.
(3) An interface reaction on the Al side occurred drastically. This was due to the difference between the melting points of Al and Cu.
(4) Tensile shear strength was increased with increasing brazing current. The brazed joint area increased with increasing brazing current. When the brazing filler metal foil is not melted, the Al–Cu brazed joints have low tensile shear strength. However, when the brazing filler metal foil is melted, the Al–Cu brazed joints have high tensile shear strength.
(5) The brazed layer mainly consists of an Al-rich layer and a Cu-rich layer. The Al-rich layer consists of Al solid solution, Al–P compound, and Cu6P or CuP2 compound. The Cu-rich layer consists of Cu solid solution, Cu–Ni alloy phase, Cu4P or CuP2 compound, and Al–Cu compound. Nickel is detected in the Cu-rich layer. Ni–Al alloy phase is precipitated at the Cu–rich layer. Sn concentrates at the interface between the brazed layer and Cu base metal. Cu–Sn compound is formed. Phosphorus exists in the overall brazed layer.
(6) Al and Cu can be joined by spot brazing with Cu–Ni–Sn–P brazing filler and a cover plate.

Figure 11. Relation between brazing current and tensile shear strength of the Al–Cu joints brazed with Cu-Ni-Sn-P brazing filler and cover plate.

Figure 12. Outside appearances of specimens after the tensile shear test.

4. Conclusions

In when a cover plate was used, tensile shear strength was increased by approximately 40 percent.
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