Wetting and spreading behavior of molten brazing filler metallic alloys on metallic substrate

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Abstract. Wetting and spreading of molten brazing filler material are important factors that influence the brazing ability of a joint to be brazed. Several investigations into the wetting ability of a brazing filler alloy and its surface tension in molten state, in addition to effects of brazing time and temperature on the contact angle, have been carried out. In general, dissimilar-metals brazing technology and high-performance brazed joint are necessities for the manufacturing field in the near future. Therefore, to address this requirement, more such studies on wetting and spreading of filler material are required for a deeper understanding. Generally, surface roughness and surface conditions affect spreading of molten brazing filler material during brazing. Wetting by and interfacial reactions of the molten brazing filler material with the metallic substrate, especially, affect strongly the spreading of the filler material. In this study, the effects of surface roughness and surface conditions on the spreading of molten brazing filler metallic alloys were investigated. Ag-(40-x)Cu-xIn and Ag-(40-x)Cu-xSn (x=5, 10, 15, 20, 25) alloys were used as brazing filler materials. A mild-steel square plate (S45C (JIS); side: 30 mm; thickness: 3 mm) was employed as the substrate. A few surfaces with varying roughness were prepared using emery paper. Brazing filler material and metallic base plate were first washed with acetone, and then a flux was applied to them. The filler, 50 mg, was placed on the center of the metallic base with the flux. A spreading test was performed under Ar gas using an electrically heated furnace, after which, the original spreading area, defined as the sessile drop area, and the apparent spreading area, produced by the capillary grooves, were both evaluated. It was observed that the spreading area decreased with increasing In and Sn content.

1. Introduction

Joining technologies are important fabrication processes, and joining-ability affects product quality. Brazing is a special joining technology and offers several advantages to the manufacturing field. Applications of brazing include heat exchanger, EGR cooler, and dissimilar-metal joining. Filler material properties, wetting and spreading by molten filler material, and interfacial reactions between molten filler and base materials are all important factors for getting a sound joint by brazing [1]. Wetting and spreading ability of molten brazing filler metallic alloy influence the brazing ability of a joint. Several investigations into wetting by and surface tension of molten brazing filler alloy have been carried out [2]. Effects of brazing time and temperature on the contact angle too have been investigated. In general, brazing of dissimilar metals and high-performance brazed joints are expected to be essential for the field of manufacturing in the near future. Consequently, wetting and spreading abilities of filler materials must be investigated in depth. Moreover, spreading of molten brazing filler
material is affected by the surface roughness and surface conditions, and especially by the interfacial reactions between the filler and base materials. In this study, the effects of the surface roughness and surface conditions on the spreading of molten brazing filler metallic alloys are investigated.

2. Experimental procedure

2.1. Base and brazing filler materials
Ag-(40-x)Cu-xIn and Ag-(40-x)Cu-xSn (x = 5, 10, 15, 20, 25; x is mass%) alloy were used as brazing filler metallic alloys [3]. Chemical compositions and temperatures were shown in Table 1. Mild steel plate, S45C, and pure nickel plate were employed as the base. Specimens with values of maximum surface roughness, $R_{\text{max}}$, of 0.15 µm, 0.55 µm, and 3.2 µm were prepared by polishing with emery paper.

| No. | Chemical compositions, mass% | Temperature, °C |
|-----|------------------------------|-----------------|
| 1   | Bal. 35 5 - | 728 776         |
| 2   | Bal. 30 10 - | 673 748         |
| 3   | Bal. 25 15 - | 610 704         |
| 4   | Bal. 20 20 - | 612 685         |
| 5   | Bal. 15 25 - | 605 677         |
| 6   | Bal. 35 - 5  | 680 767         |
| 7   | Bal. 30 - 10 | 602 718         |
| 8   | Bal. 25 - 15 | 600 680         |
| 9   | Bal. 20 - 20 | 521 640         |
| 10  | Bal. 15 - 25 | 514 586         |

2.2. Spreading test
Brazing filler alloy and base metallic plate were washed with acetone, and had a flux applied to them. The filler alloy, 50 mg, was placed on the center of the base plate with the flux. Spreading test was performed under an Ar gas atmosphere using an electrically heated furnace. Test temperatures were 640 °C, 730 °C, and 860 °C, and test duration was 20 min. After the test, the original spreading area, defined as the sessile drop area; and the apparent (halo) spreading area, which includes the original spreading area and is produced by the capillary grooves characterizing surface roughness; were evaluated, as shown in Figure 1.

![Figure 1. (a) Original spreading area (red region) and (b) apparent (halo) spreading area (including the original spreading area; blue region).](image)
2.3. Estimation methods
To investigate the effect of surface roughness and surface condition on the spreading of the molten brazing filler alloy, microstructures at the cross-section along an edge of the original spreading area were observed. Elemental distributions were analyzed using an electron probe micro-analyzer (EPMA) along an edge of the original spreading from directly above the said area.

3. Results and discussion

3.1. Wetting and spreading on mild steel plate, S45C
Typical spreading test results are shown in Figure 2. According to these results, filler material composition and surface roughness of the base metal influence the original and halo spreading areas, the latter being produced by the capillary grooves that cause the surface roughness (blue region).

| Filler          | $R_{\text{max}}$, $\mu$m |
|-----------------|-----------------------------|
|                 | 0.15                        | 0.55                        | 3.2                         |
| Ag-35Cu-5Sn     |                             |                             |                             |
| Ag-15Cu-25Sn    |                             |                             |                             |

Figure 2. Effects of filler material composition and surface roughness on spreading area. Blue region shows the halo spreading area, produced only by the capillary grooves, that does not include original spreading area.

Formation of an alloyed layer, which can be caused by an unrestrained interfacial reaction between the molten filler and the base metal during spreading, was not observed in EPMA results at the cross-section along an edge of the original spreading area. Therefore, it can be inferred that interfacial reaction hardly influenced the spreading of the molten filler in this study. Figures 3, 4, 5, and 6 show the effects of surface roughness on original and halo spreading areas. In the case of fillers 1 and 6 from Table 1, the halo spreading area increased dramatically with increasing surface roughness. Figure 7 shows the scanning electron microscopy (SEM) image of the halo spreading area as viewed from directly above. In conjunction with this image, the elemental distribution results by EPMA show that a white phase, corresponding to a Ag solid solution containing In as the solid solute, and a grey phase, corresponding to a Cu solid solution, are present in fillers 1 and 6, and that consequently liquation did not occur. Figure 7 also shows that the molten brazing filler solidified along open microgrooves at the halo spreading area. It is appeared that a halo spreading area is caused by spreading of molten filler through open microgrooves [4]. Figure 8 shows the surface microstructure of the base metal after heat treatment. According to Figures 7 and 8, a small white phase at the halo spreading area was formed.
along the austenite grain boundaries at test temperature. The halo spreading area decreased slightly with increasing surface roughness in that case of filler 5 (Ag-15Cu-25In) and increased slightly with increasing surface roughness in that case of filler 10 (Ag-15Cu-25%Sn). Detailed explanations for this phenomenon are as yet unknown. In that case of Ag-Cu-In fillers, the original spreading area decreased slightly with increasing surface roughness. However, the original spreading area was not influenced by surface roughness in that case of Ag-Cu-Sn fillers.

**Figure 3.** Effect of $R_{\text{max}}$ surface roughness on original and halo spreading areas for filler 1 (Ag-35Cu-5In). Temperature was 860°C. Duration was 20 min.

**Figure 4.** Effect of $R_{\text{max}}$ surface roughness on original and halo spreading areas in for filler 5 (Ag-15Cu-25In). Temperature was 860 °C. Duration was 20 min.

**Figure 5.** Effect of $R_{\text{max}}$ surface roughness on original and halo spreading areas for filler 6 (Ag-35Cu-5Sn). Temperature was 860 °C. Duration was 20 min.

**Figure 6.** Effect of $R_{\text{max}}$ surface roughness on original and halo spreading areas for filler 10 (Ag-15Cu-25Sn). Temperature was 860 °C. Duration was 20 min.

**Figure 7.** Surface microstructure at the halo spreading area.

**Figure 8.** Surface microstructure of the base metal after only heat treatment.
| Filler   | BEI     | Ag       | Cu       | In       | Ni       |
|----------|---------|----------|----------|----------|----------|
| Ag-35Cu-5In | ![Image](image1.png) | ![Image](image2.png) | ![Image](image3.png) | ![Image](image4.png) | ![Image](image5.png) |
| Ag-25Cu-15In | ![Image](image6.png) | ![Image](image7.png) | ![Image](image8.png) | ![Image](image9.png) | ![Image](image10.png) |

10mm

| Filler   | BEI     | Ag       | Cu       | Sn       | Ni       |
|----------|---------|----------|----------|----------|----------|
| Ag-35Cu-5Sn | ![Image](image11.png) | ![Image](image12.png) | ![Image](image13.png) | ![Image](image14.png) | ![Image](image15.png) |
| Ag-25Cu-15Sn | ![Image](image16.png) | ![Image](image17.png) | ![Image](image18.png) | ![Image](image19.png) | ![Image](image20.png) |

10mm

**Figure 9.** Elemental distributions at the halo spreading area on pure Ni plate. Test temperature: 860°C. Test duration: 20 min. Surface roughness: 3.2 µm.

3.2. *Wet and spread on pure Ni plate*

Figure 9 shows the elemental distributions at a halo spreading area on pure Ni plate, according to which, liquation occurred during brazing. Liquation in brazing is defined as the tendency of the lower-
melting constituents of the brazing filler alloy to separate out and flow away by capillary action from the higher-melting constituents upon heating. [5] When liquation occurs, low-melting constituents spread preferentially. However, Ag, despite being high-melting constituent, too spreads preferentially. It thus appears that different phenomena occur simultaneously. In this study, Ag and In spread on the base metal along the front edges of the spreading area during wetting and spreading in the case of the Ag-Cu-In filler. Solidified In, especially, was detected spread across the entire halo spreading area after wetting and spreading. On a Ni plate, the Ag and In components of the molten alloy spread preferentially. Therefore, Ag and In constituents of Ag-Cu-In fillers affect the wetting-ability and the halo spreading area. According to the EPMA results, in that case of Sn-based filler alloys, the Ag component of the molten filler spreads preferentially on a pure Ni plate. A molten brazing filler composed mainly of Ag has relatively high liquidus temperature, as can be seen from the Ag-Cu-Sn ternary phase diagram [6]. It is thus inferred that liquation does not occur in the filler alloys studies.

4. Conclusions
In this study, the effects of surface roughness and surface condition on the spreading of molten brazing filler materials were investigated. The results are as follows.
(1) Original spreading area, which is defined as the sessile drop area, and the halo spreading area, produced by capillary grooves, were both observed.
(2) The halo spreading area formation is caused by the spreading of molten filler through open microgrooves.
(3) The interfacial reaction between molten brazing filler and base metal hardly influences spreading of the molten filler.
(4) Molten alloys containing mainly Ag and In spread preferentially on a Ni base plate. Therefore, Ag and In, which are both constituents of Ag-Cu-In fillers, affect the wetting-ability of the filler.

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