Brazing of copper to stainless steel with a low-silver-content brazing filler metal

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Abstract. The brazing of copper to stainless steel (SUS304 JIS) was performed using a low-silver-content brazing filler metal, Ag-50Cu, under an Ar gas atmosphere with a conventional furnace, owing to the potential economic benefits of using low-silver-content filler metals. The brazeability of the low-silver-content brazing filler metal to copper and SUS304 was investigated. A good joint was obtained, and a drastic dissolution reaction occurred at the copper side. Molten BAg8 penetrated along the crystal grain boundary of the copper base metal when BAg8 was used as the filler metal. This was caused by the dissolution of Ni from the stainless steel into the molten filler metal. Ag-50Cu, which was investigated in this work, can be used instead of BAg8 filler metal.

1. Introduction

Cu/SUS304 (JIS) joints are used extensively in refrigerators [1, 2]. The brazing of a copper pipe to a stainless steel pipe has been traditionally performed using Ag-based brazing filler metals. The eutectic Ag-based filler metal JIS BAg8 exhibits good brazing ability; however, it is expensive because of its high Ag content. A low-silver-content brazing filler metal is less expensive; however, it has a higher liquidus temperature compared to eutectic Ag-based filler metals, as indicated in Figure 1. High brazing temperatures inhibit the joining to the base metal, and the fluidity of brazing filler metals diminishes with increasing Cu content. Therefore, in this study, the brazing of copper to stainless steel was performed using a low-silver-content brazing filler metal. The brazeability of the low-silver-content brazing filler metal is investigated and discussed.

Figure 1. Ag–Cu phase diagram.
2. Experimental procedure

2.1 Base metal and brazing filler metal
Copper (phosphorous-deoxidized copper), austenitic stainless steel (SUS304 JIS), and ferritic stainless steel (SUS444 JIS) were used as microstructure observation specimens. A schematic diagram of the pipe-joint specimen used in this work is presented in Figure 2. The chemical compositions of the base metals are listed in Table 1. Ag-based (BAg8 JIS) and low-silver-content brazing filler metal wires were used as the brazing filler metals. The chemical compositions and melting temperatures of the brazing filler metals are listed in Table 2. Brazing was performed under an Ar gas atmosphere using a conventional furnace. The brazing temperatures were 840 °C and 940 °C, and the brazing time was 2 min.

2.2 Microstructure observation and EPMA analysis
The microstructures of cross-sections were observed using an optical microscope, and the elemental distributions were analyzed by electron probe micro-analysis (EPMA).

2.3 Tensile shear tests
The tensile shear strength of a Cu/SUS304 brazed joint was measured to estimate the mechanical properties. A schematic diagram of the single-lap specimen is presented in Figure 3. The tensile shear strength was measured using an Instron® 3367. The cross-head moving speed was 1 mm/min.

2.4 Micro-Vickers hardness tests
The hardness at the brazed joint was measured using a micro-Vickers hardness tester. The applied load was 4.0 N, and the holding time was 10 s.

![Figure 2. Schematic diagram of the pipe joint.](image)

![Figure 3. Schematic diagram of the single lap.](image)

| Table 1. Chemical compositions of the base metals. |
|-----------------------------------------------|
| **Type** | **Chemical compositions, mass%** | \multicolumn{3}{c|}{**Temperature, °C**} |
|         | Cu | P | Fe | C | Si | Mn | S | Ni | Cr |
| Cu      | 99.96 | 0.025 | - | - | - | - | - | - | - |
| SUS304  | - | - | Bal. | 0.04 | 0.59 | 0.28 | 0.003 | 9.13 | 18.20 |
| SUS444  | 0.2 | 0.035 | Bal. | 0.01 | 0.29 | 1.01 | 0.002 | 0.17 | 18.37 |

| Table 2. Chemical compositions and solidus and liquidus temperatures of the brazing filler metals. |
|-----------------------------------------------|
| **Type** | **Chemical compositions, mass%** | **Temperature, °C** |
|         | Ag | Cu | Solidus | Liquidus |
| BAg8    | 71.0–73.0 | Bal. | 780 | 780 |
| Low-silver-content | 50 | 50 | 780 | 880 |
3. Results and discussion

3.1 Microstructure observation and EPMA analysis

Figure 4 shows typical cross-sections of the Cu/SUS304 brazed joint. BAg8 exhibits excellent fluidity on the basis of its good fillet shape; this good fluidity is attributed to the eutectic composition of the filler metal. However, the fluidity of the low-silver-content brazing filler metal was inferior to that of BAg8.

According to the results in Figure 4, dissolution of the Cu base metal occurred preferentially. In the case where the low-silver-content filler was used, the dissolution of the Cu base metal was more extensive compared with the case of BAg8 because of the relative high liquidus temperature of the low-silver-content filler.

When BAg8 was used, molten BAg8 penetrated along the crystal grain boundaries of the copper base metal. Gabbay et al. reported that copper brazed with BAg8 does not result in grain-boundary damage [3, 4]. Figure 5 presents the distributions of elements at the Cu/SUS304 joint brazed with BAg8 and with the low-silver-content filler, obtained by EPMA. These results show that molten BAg8 containing Ni, which originates from the stainless steel base metal during brazing, penetrates along the crystal grain boundary of the copper base metal. This is caused by dissolution of Ni from the stainless steel to the molten filler [5, 6].

Copper base metal was brazed with BAg8 and low-silver-content filler to ferrite stainless steel that did not contain Ni. Figure 6 shows typical cross-sectional microstructures at the Cu/ferrite stainless steel brazed joint. These results show that when the Cu/ferrite stainless steel joint was brazed with BAg8, no grain boundary penetration occurred. When a Ni-bearing base metal such as austenitic stainless steel was brazed to copper with BAg8, grain boundary penetration into the Cu base metal was observed.

3.2 Tensile shear tests

Figure 7 presents the results of the tensile shear tests of the Cu/SUS304 brazed joint and the tensile strength of the base metals. In the single-lap shear test, a fracture occurred at the copper base metal. Good joint shear strength was achieved in this study, and the tensile shear strength of the joints brazed with low-silver-content brazing filler metal was approximately equal to that of the joints brazed with BAg8. Numerous primary crystals of Cu solid solution formed at the brazed layer with low-silver-content brazing filler metal, as compared to that with BAg8; these phases did not adversely affect the joint strength.

3.3 Micro-Vickers hardness tests

Figure 8 presents the results of the micro-Vickers tests of the Cu/SUS304 brazed joint. The micro-Vickers hardness was measured at the base metals and the brazed layer. These results showed that the hardness at the Cu/SUS304 joint brazed using BAg8 was similar to that at the joint brazed using the low-silver-content filler metal. Thus, the low-silver-content brazing filler metal can be used as an alternative to BAg8.
Figure 4. Typical cross-sections of the Cu/SUS304 brazed pipe joint.

Figure 5. Elemental distributions determined by EPMA at the Cu/SUS304 pipe joint brazed using BAg8 and low-silver-content brazing filler metals.
Figure 6. Typical cross-sections at the Cu/SUS444 plate joint brazed using BAg8 and low-silver-content brazing filler metals.

Figure 7. Tensile shear test results of the Cu/SUS304 joint brazed with BAg8 filler metal (840 °C, 2 min) and with the low-silver-content filler metal (940 °C, 2 min).

Figure 8. Micro-Vickers hardness test results for the Cu/SUS304 joint brazed with the BAg8 filler metal (840 °C, 2 min) and the low-silver-content filler metal (940 °C, 2 min).
4. Conclusions
Copper and SUS304 were brazed using a low-silver-content brazing filler metal. The brazeability was investigated based on the microstructural observations and EPMA analyses. The following results were obtained:

(1) A low-silver-content brazing filler metal exhibits good brazing ability.

(2) The fluidity of the low-silver-content brazing filler metal was approximately equal to that of BAg8.

(3) A dissolution reaction occurred at the copper side when the low-silver-content brazing filler metal was used. In contrast, molten BAg8 penetrated along the crystal grain boundary of the copper base metal when BAg8 was used. Penetration of the molten BAg8 filler along the crystal grain boundary was caused by the dissolution of Ni from the stainless steel into the molten filler.

(4) The Ag-50Cu low-silver-content brazing filler metal can be substituted for BAg8.

References
[1] Fukikoshi T, Watanabe Y, and Miyazawa Y 2013 Pros. JWS. 93 10
[2] Fukikoshi T, Watanabe Y, and Miyazawa Y 2013 Proc. Int. Symp. Interfacial Joining and Surface Technology(IJST2013) 147
[3] Gabbay R, Wagner H. Z, Dirnfeld S. F, and Ramon J. J 1990 Weld. J. 69 10 378
[4] Dirnfeld S F, Ramon J J, Gabbay R, and Wagner H J 1991 Mater. Charact. 26 1 17
[5] Siewert T A, Heine R W 1977 Metall Trans A 8 3 515
[6] Luo H-T, Chen S-W 1996 J Mater Sci 31 19 5059
[7] Miller V. R, Schwanke A. E 1978 Weld J. 57 10 303