Effect of stainless steel chemical composition on brazing ability of filler metal

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Abstract. Many kinds of stainless steel have been used in the engineering field. So it is necessary to investigate the effect of SUS chemical compositions on the brazing ability of filler metal. In this study, SUS315J containing Cr, Ni, Si, Cu, and Mo was employed as a base metal. Excellent spreading ability of the molten nickel-based brazing filler on SUS315J was obtained as compared with that on SUS316. Copper and silicon influenced the significant spreading ability of the filler.

1. Introduction
Many kinds of stainless steel have been developed, and they have been used for many applications ranging from kitchenware and tableware to automobiles, construction, and electrical applications. They have been used for domestic hot water services such as electric hot water tanks and kerosene-burning water heaters [1]. A few alloying elements such as Cu or Si are added to improve the properties of stainless steel. However, the influence of the addition of a few alloying elements to the joining ability (brazing ability) has not been investigated until now. SUS315J2 stainless steel (JIS), which has good stress corrosion cracking (SCC) resistance and crevice corrosion resistance properties, has been developed [1]. SUS315J2 contains Cu and Si as alloying elements to improve SCC resistance properties [2].

The brazing ability of a paste-type Ni-based brazing filler metal as an all-purpose brazing filler metal to SUS315J2 was investigated in this study.

2. Experimental procedure

2.1. Base Metal and Brazing Filler Metal
SUS315J2 stainless steel (JIS) was employed as the base material. The chemical composition of this stainless steel is shown in Table 1; SUS316 stainless steel was used as the standard. Paste-type Ni–Cr–Si–P and BNi2 brazing filler metals were used in this study. The Ni–Cr–Si–P brazing filler metal did not contain B and had a relatively low melting point with good corrosion resistance properties [3-4]. The chemical composition of both fillers is shown in Table 2.

2.2. Specimens
A T-joint specimen was used to investigate fillet formability and observe the cross-sectional microstructure at the brazed joint. A single-lap specimen was used to estimate the mechanical properties of the brazed joint. Spreading tests were employed to investigate the spreading ability of the...
molten Ni–Cr–Si–P and BNi₂ brazing filler metals on the SUS315J2 stainless steel (JIS). Schematic diagrams of each specimen are shown in Figures 1 and 2.

Table 1. Chemical compositions of SUS315J2 and SUS316 (JIS) used in this study.

| SUS No. | Fe  | C   | Si  | Mn  | P   | S   | Ni  | Cr  | Mo  | Cu  |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 315J2   | Bal.| <0.08 | 2.5-4.0 | <2.0 | <0.045 | <0.03 | 11.0-14.0 | 17.0-20.5 | 0.5-1.5 | 0.5-3.5 |
| 316     | Bal.| <0.08 | <1.0 | <2.0 | <0.045 | <0.03 | 10.0-14.0 | 16.0-18.0 | 2.0-3.0 | -   |

Table 2. Chemical compositions and temperature of brazing filler metals used in this study.

| Chemical compositions (mass%) | Temperature (°C) |
|------------------------------|------------------|
| Ni  | Cr  | Si  | Fe  | P   | B   | Solidus | Liquidus |
| BNi2 | Bal. | 6.0-8.0 | 4.0-5.0 | 2.5-3.5 | - | 2.75-3.50 | 970 | 1000 |
| Ni-Cr-Si-P | Bal. | 27.5-31.5 | 3.8-4.2 | - | 5.6-6.4 | - | 980 | 1030 |

Figure 1. Schematic diagram of T-joint specimen.

Figure 2. Schematic diagram of spread test specimen.

2.3. Brazing Process and Estimation Method

Before the spreading test, a constant amount of paste-type brazing filler metal was placed on the center of the SUS315J2 plate using a dispenser. After the test or after solidification of the molten filler on the stainless steel plate, the shape of the solidified brazing filler metal region was observed and its area was measured. The spreading area was defined as the measured area. The spreading ability of the molten brazing filler metal was investigated by using the measurement results of the spreading area. Furthermore, the edge of the solidified brazing filler metal region was observed and analyzed with an electron probe microanalysis (EPMA) system in order to investigate the mechanism behind the spreading of the molten brazing filler metal.

Brazing was done by using a vacuum-type (5 × 10⁻³ Pa) conventional electric heated furnace under Ar gas (purity: 99.995%) atmosphere or vacuum atmosphere. The brazing temperatures were 1080 and 1130 °C with consideration of the liquidus temperature of the brazing filler metal. The brazing times were 5 or 30 min.

The top view of the specimens and the cross-sectional microstructures at the brazed joints of the T-joint specimens were observed with an optical microscope (OM) and scanning electron microscope.
(SEM). Also, elemental distributions were analyzed with using an EPMA system. The mechanical properties of the brazed joint were estimated with a single-lap specimen and shear tests.

3. Results and Discussion

3.1. Outside appearance and cross-sectional microstructure of the T-joint specimen

Figure 3 shows the outside appearance of the T-joint specimens brazed with the Ni–Cr–Si–P filler alloy. Excellent wettability and spreading ability of the Ni–Cr–Si–P filler on SUS315J2 as compared with that on SUS316 were obtained.

The EPMA analysis of the interfacial microstructure of the SUS315J2 joint brazed with Ni–Cr–Si–P was similar to that of the SUS316 brazed joint, as shown in Figure 4. We did not observe an alloyed layer or alloy phase containing Cu, Si, or Mo by interfacial reaction during wetting and spreading at the brazed interface between the base metal and brazed layer through either SEM observations or EPMA analytical results.

3.2. Spreading test

Figure 5 shows the spreading test results and Figure 6 shows the spreading area measurement results as a function of brazing atmosphere. According to these results, good joinability of SUS315J2 was obtained. In the case of brazing under vacuum atmosphere, excellent wettability of the Ni–Cr–Si–P filler to SUS315J2 was obtained as compared with SUS316. On the other hand, in the case of brazing under Ar gas atmosphere, the wettability of the Ni–Cr–Si–P filler to SUS315J2 was similar to that to SUS316.

Figure 7 shows typical top view SEM images of the edge of the solidified brazing filler metal region and typical EPMA elemental distribution in the case of vacuum atmosphere. It was found that similar surface microstructures of the solidified brazing filler metal regions formed. Surface conditions such as grain boundary grooves of the base materials hardly influenced the wetting and spreading phenomenon of the molten filler in both cases. It is recognized that the molten filler solidified from the edge of the spreading filler metal region and that the influence of solidification shrinking was minimal. Consequently, it appears that the driving force for the spreading phenomenon of the molten brazing filler metal can be estimated from elemental distribution results.

According to the elemental distribution, these results, in that case of using SUS315J2, it is recognized that Cu is contained in molten brazing filler metal. And in that case of using SUS316 as standard, it is recognized that Cu is hardly contained in molten brazing filler metal. It is considered that existence of Cu and Si element in molten brazing filler is caused by dissolution phenomenon of the SUS315J2 during brazing. Consequently, it appears that the presence of Cu and Si changed the specific characteristics of the molten brazing filler metal and that spreading progressed as a result of these changes.

Similar elemental distributions results were obtained in the case of brazing under Ar gas atmosphere. An Ar gas atmosphere is not a reducing atmosphere, and thus the formation of a Cr oxide thin film on the stainless steel surface decreased the effect of changes by Cu or Si.

The effect of the addition of Cu to the brazing filler metal on spreading ability was investigated. Figure 8 shows top views of T-joint specimens brazed with the Ni–Cr–Si–P filler alloy with added Cu. Figure 9 shows the effect of Cu addition on the spreading area. The addition of Cu to the brazing filler metal and increasing the amount of added Cu facilitated spreading of the brazing filler metal slightly in both stainless steels. Figure 10 shows the effect of adding Si to the brazing filler metal on the spreading ability. According to the results, the addition of Si to the Ni–Cr–Si–P filler affected the spreading ability of SUS315J2 slightly.
Figure 3. Typical outside appearance of the T-joint specimens brazed with Ni–Cr–Si–P filler alloy. Brazing temperature was 1080 °C. Brazing time was 5 min. Brazing atmosphere was vacuum.

Figure 4. Typical elemental distributions at the joint brazed with Ni–Cr–Si–P filler alloy. Brazing temperature was 1080 °C. Brazing time was 5 min. Brazing atmosphere was vacuum.
| Atmosphere | Base Metal | Ar gas | Vacuum |
|------------|-----------|--------|--------|
|            | SUS315J2  | BNi₂   | Ni–Cr–Si–P |
|            | SUS316    |        |         |

**Figure 5.** Typical outside appearance of the spread specimen after test. Brazing temperature was 1080 °C. Brazing time was 5 min.

**Figure 6.** Spreading area measurement results. Brazing temperature was 1080 °C. Brazing time was 5 min.
**Figure 7.** Typical top view outside appearance of the spread specimen and elemental distributions at the edge of spread area with EPMA. Brazing temperature was 1080 °C. Brazing time was 5 min. Brazing atmosphere was vacuum.
| Base metal | Vacuum Ni–Cr–Si–P | Vacuum Ni–Cr–Si–P + 1 mass% Cu | Vacuum Ni–Cr–Si–P + 2 mass% Cu |
|------------|------------------|-------------------------------|-------------------------------|
| SUS315J2   | ![Image 1](image1) | ![Image 2](image2) | ![Image 3](image3) |
| SUS316     | ![Image 4](image4) | ![Image 5](image5) | ![Image 6](image6) |

**Figure 8.** Effect of Cu addition to Ni–Cr–Si–P filler on spread area. Brazing temperature was 1080 °C. Brazing time was 5 min.

**Figure 9.** Spreading area measurement results. Brazing temperature was 1080 °C. Brazing time was 5 min.
The normal thickness of a Cr₂O₃ thin film as a passivation film on stainless steel is 1–3 nm [5]. On the other hand, Si oxidizes on the stainless steel with increasing temperature when the stainless steel contains Si [6]. The self-diffusion coefficient of metallic ions in a passivation film on stainless steel is extreme low at 1000 °C [7]. Therefore, it was difficult to imagine that Si was oxidized by oxygen from the outer atmosphere.

The formation energy of Cr₂O₃ was higher than that of Si oxide [8], and so it appeared that Cr₂O₃ was reduced by the oxidation of Si on the stainless steel. Also, Cr₂O₃ was reduced by the extremely low oxygen partial pressure caused by the clean vacuum atmosphere. The passivation film on stainless steel was thus broken by the reduction of the Cr₂O₃ thin film. A molten Ni-based brazing filler metal was in direct contact with the metallic surface of the stainless steel, as shown in Figures 5 and 8. Extreme wetting and spreading took place in the case of using SUS315J2 stainless steel.

4. Conclusions
The brazing ability of a paste-type Ni-base brazing filler metal as an all-purpose brazing filler metal for SUS315J2 stainless steel (JIS) was investigated in this study, and the following results were obtained:

1. A sound SUS315J2 brazed joint with a Ni–Cr–Si–P brazing filler metal was obtained.
2. In the case of brazing under vacuum atmosphere, excellent wettability of the Ni–Cr–Si–P filler to SUS315J2 was obtained as compared with that to SUS316.
3. It appears that the presence of Cu and Si changed the specific characteristics of the molten brazing filler metal and that spreading was facilitated by these changes.
4. It appears that a passivation film on the stainless steel was broken by the reduction of the Cr₂O₃ thin film. The molten Ni-based brazing filler metal was in direct contact with the metallic surface of the stainless steel. Extreme wetting and spreading took place in the case of using SUS315J2 stainless steel.
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