Brazing of Inconel 600 and SUS304 Stainless Steel with Used of Rapidly Solidified Nickel-Base Brazing Foil

Yasuyuki Miyazawa† and Tadashi Ariga

Department of Metallurgical Engineering, School of Engineering, Tokai University, 1117 Kitakaname, Hiratsuka-shi, Kanagawa 259-12, Japan

Recently, flexible nickel-base brazing foil has been prepared by rapid solidification technology. So that it seemed that the brazing, which used the flexible nickel-base brazing foil, is a more effective method for joining having a large joining area than the brazing which uses the powder form nickel-base brazing filler metal. Therefore it seems that the brazing, which uses the nickel-base brazing foil, has been an effective method for producing clad materials.

In this study, the clad material which have been brazed with the nickel-base heat resistant alloy; Inconel 600 on AISI304 stainless steel has been produced by the brazing using three types of nickel-base brazing foils. The three types of nickel-base brazing foils are 7Cr(4.5Si-7.0Cr-3.0B-3.0Fe-NiBal.), 5Cr(4.5Si-5.0Cr-3.0B-3.0Fe-NiBal.) and 10Cr(4.5Si-10.0Cr-3.0B-3.0Fe-NiBal.). Brazing was done in an electrical resistant furnace in an argon gas atmosphere. The brazing temperatures employed in this study were 1050, 1100, 1150, 1200 and 1250°C and the brazing times were 10, 30, 60 and 120 min for all types of brazing foils.

The property of the joint was estimated by the mechanical properties, microstructures and distributions of the elements which were investigated by SEM and EPMA.

The brazed joint was obtained for all of brazing conditions in this study. The shear strength of the specimen increased with increasing brazing time except at 1050°C. At 1050°C, the shear strength of the specimen was not influenced by brazing time. In this case, the break of the specimen during the shear test occurred in the brazed layer. At 1250°C, the value of 450 MPa was obtained as the maximum shear strength in this study; the break of the specimen occurred in the base metal.

The shear strength of the specimen increased with increasing brazing temperature. The shear strength of the specimen increased with increasing chromium content in the brazing foil to 7 mass%.

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Keywords: brazing, nickel base brazing foil, clad material, Inconel 600, AISI304 stainless steel, shear strength

I. Introduction

Nickel-base brazing filler metals are primarily used where extreme heat and corrosion resistance are required. They are commonly used in the manufacture of jet and rocket engines, chemical processing equipment, and nuclear reactor components. These brazing filler metals are normally supplied as powders. Recently, flexible nickel-base brazing foil has been prepared by rapid solidification technology, which has compositions that previously could only be utilized in powder form, or as powder-filled pastes. The most important advantage of this rapidly solidified nickel-base brazing foil is their ductility; the brazing foils is able to put on the complex joint. The brazing, which uses the flexible rapidly solidified brazing foil, is a more effective method for joining a large area than the brazing which uses the powder form nickel-base brazing filler metal.

It has been defined that the clad materials are the materials which are metallurgically joined with some heat or corrosion resistant materials; e.g., stainless steel and nickel-base heat resistant alloys, on the low-cost materials; e.g., the mild steel by rolling, explosive joining, internal chill or diffusion methods. The clad materials has a wide and/or large joining area.

Therefore it seems that the brazing, which uses the rapidly solidified brazing foil, is an effective method for producing clad materials.

In this study a simulated clad material by brazing the nickel-base heat resistant; Inconel 600 to SUS304 stainless steel with various nickel-base brazing foils was produced. The property of the joint made with the nickel-base brazing foil was studied for producing the clad materials. This paper, in particular, describes:

1. The relationship between the shear strength and the brazing factor.
2. The relationship between the shear strength and the cross-sectional microstructures at the brazed joint.
3. The influence of the interface reactions, including the migration of the elements contained in the nickel-base brazing foil and the base metal, on the cross-sectional microstructures and the shear strength at the brazed joint.

† Graduate Student, Tokai University.
II. Experimental Procedure

The chemical compositions of three types of nickel-base brazing foils used in this study are shown in Table 1. The thickness of the brazing foil was approximately 70 μm. In this study, the base metals were a nickel-base heat resistance alloy, Inconel 600 and stainless steel (SUS 304).

First, the effect of the surface roughness of the both base metals on the shear strength was investigated as shown in Fig. 1. The shear strength of the specimen was not influenced by the surface roughness in the case of 1250°C. However, in the case of 1050°C, a maximum shear strength was shown when the surface roughness was 0.2 μm ($R_{max}$). Therefore the value was selected as the surface roughness in this study.

The joint area of the base metals was polished and washed with acetone before the brazing treatment. Prepared brazing foils were placed between Inconel 600 and the stainless steel as shown in Fig. 2. The brazing was done in an electrical resistant furnace in an argon gas atmosphere.

<table>
<thead>
<tr>
<th>Brazing foils</th>
<th>Chemical compositions (mass%)</th>
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<tbody>
<tr>
<td>5Cr</td>
<td>Ni</td>
</tr>
<tr>
<td>Bal.</td>
<td>3.0</td>
</tr>
<tr>
<td>7Cr</td>
<td>Bal.</td>
</tr>
<tr>
<td>10Cr</td>
<td>Bal.</td>
</tr>
</tbody>
</table>

The brazing temperatures employed in this study were 1050, 1100, 1150, 1200 and 1250°C and the brazing times were 10, 30, 60 and 120 min for all types of brazing foils.

The brazability was estimated by the mechanical properties and the distribution of the elements at the brazed joints. For the measuring method of mechanical properties, "Test Specimen and Method of Making Shear Test of Clad Plate" (ASTM-A264)\(^3\) was applied basically as shown in Fig. 3. The distributions at the brazed joint of the elements was investigated by SEM (scanning electron microscope) and EPMA (electron probe microanalyzer).

III. Results and Discussion

1. Shear strength of the specimen

The shear strength of the specimen made with 5Cr increased with increasing brazing time except at 1050°C, as shown in Fig. 4. The shear strength was saturated by brazing for a long time at every brazing temperature except at 1050°C as shown in the figure. The shear strength of the specimen brazed at 1050°C was hardly influenced by the brazing time.
The effect of the brazing temperature on the shear strength of the specimen made with 5Cr is shown in Fig. 5. According to this figure, the shear strength increased with increasing brazing temperature at every brazing time. And the shear strength was saturated at high brazing temperatures.
In the case of other types of brazing foils; 7Cr and 10Cr, the shear strength of the specimen increased with increasing brazing time and temperature as shown in Figs. 6 and 7.

Figure 8 showed the effect of the chromium content in the brazing foil on the shear strength. The shear strength of the specimen increased with increasing chromium content in the brazing foils to 7 mass% under all the brazing conditions. Over 7 mass%, the shear strength was fixed approximately.

2. Cross-sectional microstructures

The typical cross-sectional microstructures at the brazed joint are shown in Fig. 9. These cross-sectional microstructures of the specimen consisted of three types of the microstructures. First, second and third types were the cross-sectional microstructures of Inconel 600, stainless steel and the brazed layer, respectively.

The precipitation phase existed in both base metals as shown in Fig. 9. The precipitation within both base metals appeared such as the layer and the amount of precipitation decreased with increasing brazing time. Especially, the precipitation within Inconel 600 disappeared faster than that within the stainless steel.

The precipitation within Inconel 600 disappeared at much faster brazing time and lower brazing temperature than that within the stainless steel, because it appeared that the amount of the boron diffused from the brazing foil to Inconel 600 was smaller than that of the boron diffused from the brazing foil into the stainless steel.

And the microstructure at Inconel 600 side is the homogeneous microstructure. However, the disappearance of the precipitation in Inconel 600 did not improve the shear strength. On the other hand, the disappearance of the precipitation within the stainless steel improved the shear strength.

Next the effects of chromium content in the brazing foils and the brazing conditions on the cross-sectional microstructures at the brazed joint are shown in Figs. 10 and 11. According to Fig. 10, in the case of 1050°C, a similar cross-sectional microstructure of the brazed joint was obtained regardless of the type of the brazing foil. In the case of 1050°C, the break occurred at the brazed layer. In short, the strength of the brazed layer depended upon the strength of the specimen. Therefore it seemed that the chromium content in the brazing foil depended upon the strength of the specimen.

According to Fig. 11, in the case of 60 min, the precipitation in the stainless steel was decreased with increasing chromium content in the brazing foil. In the case of 120 min, a homogeneous microstructure appeared regardless of the type of the brazing foils.

3. Analyzed results

The elemental distributions at the brazed joint including the precipitation by SEM and EPMA examinations are shown in Figs. 12 and 13. EPMA revealed that the precipitation within both base metals contained the chromium and boron elements. Therefore it seemed that the precipitation is boride\(\). Boron was diffused from the brazing foil into the stainless steel more remarkably compared with to Inconel 600 as shown in Fig. 12.

The boron-rich region coincided with the chromium-rich region and the relatively low nickel and iron concentrations within the stainless steel. Therefore it seemed that the diffusion of boron from the brazing foil to the stainless steel was caused by chromium contained in the stainless steel\(\).

The boron-rich region coincided with the grain boundary of the stainless steel within the base metal. Therefore it seemed that the boron diffused mainly from the brazing foil to the stainless steel along the grain boundary of the stainless steel\(\).

It seemed that the precipitation within the stainless steel was the barrier for the diffusion of chromium from the stainless steel to the brazed layer. And the shear strength increased with decreasing amount of the precipitation in the stainless steel. The shear strength increased with diffusion of the chromium element from the stainless steel to the brazed layer. In short, the diffusion of chromium from the stainless steel to the brazed layer led to the high strength of the specimen.

IV. Conclusions

In this study a simulated clad material by brazing Inconel 600 to SUS304 stainless steel with various nickel-base brazing foils was produced. The brazability of the brazing foil was then studied for producing clad materials. In order to evaluate the brazability of these foils.
Fig. 9  Cross-sectional microstructures at the brazed joint made with 10Cr. Brazing temperature: 1050°C.
<table>
<thead>
<tr>
<th>Brazing filler metal</th>
<th>Brazing temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1050 °C</td>
</tr>
<tr>
<td>5Cr</td>
<td>![Image]</td>
</tr>
<tr>
<td>7Cr</td>
<td>![Image]</td>
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<tr>
<td>10Cr</td>
<td>![Image]</td>
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1: Inconel 600  2: Brazed layer  3: SUS304

Fig. 10  Effect of Cr element content and brazing temperature on the microstructure at the brazed joint. Brazing time: 10 min.
<table>
<thead>
<tr>
<th>Brazing filler metal</th>
<th>60min</th>
<th>120min</th>
</tr>
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<tbody>
<tr>
<td>5Cr</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>7Cr</td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td>10Cr</td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
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1: Inconel 600  2: Brazed layer  3: SUS304
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Fig. 11 Effect of Cr element content and brazing time on the microstructure at the brazed joint. Brazing temperature: 1200°C.
Fig. 12  SE image and the elemental maps of Ni, Cr, Fe, B, Si and C at the brazed joint made with 10Cr.
Brazing temperature: 1050°C, Brasling time: 60 min.
Fig. 13  SE image and the elemental maps of Ni, Cr, Fe, B, Si and C at the brazed joint made with 7Cr. Brazing temperature: 1050°C, Brazing time: 60 min.
(1) The brazed joint with a maximum strength of about 400 MPa was obtained.

(2) The shear strength was hardly affected by the brazing time; the shear strength increased with increasing brazing time.

(3) It seemed that the precipitation within the stainless steel was the barrier to the diffusion of chromium from the stainless steel to the brazed layer. The shear strength of the specimen increased with decreasing amount of the precipitation within the stainless steel.

REFERENCES