A Study of the Brazeability of Nickel-Based Brazing Filler Metal Foil for Joining Nickel Base Metal to Mild Steel Base Metal

Longer brazing times appear to have contributed to the diffusion of boron, which was a factor in improving shear strength

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ABSTRACT. A nickel alloy base metal, Alloy 600, was clad to a mild steel base metal, SM41B. Four different nickel filler metals in foil form were tested. The brazeability was measured by the resulting shear strength, the joint microstructure and the distribution of elements across the joint.

The microstructure consisted of alpha nickel and/or eutectic structure. The shear test failure occurred in the filler metal for all types of brazing filler metals. If the eutectic centerline structure was produced in the brazed joint, the failure occurred through the eutectic structure. As the amount of eutectic alloy in the joint decreased, the shear strength increased. The maximum shear strength observed on this type of specimen was about 310 MPa (45 ksi) for each of the four brazing filler metals tested. The elemental distributions of nickel, chromium and boron were concentrated in the eutectic structure. It appears that the migration of boron influenced the reduction of the eutectic structure.

It was concluded that when the eutectic structure forms in the brazed joint, lower shear strength values can be expected, and with longer brazing times, the diffusion of boron into the base metal improves the shear strength of the specimen. At the same time that the eutectic structure disappeared, the diffusion of chromium and/or iron into the joint improved the shear strength of the specimen.

Introduction

Nickel-based brazing filler metals are primarily used where extreme heat and corrosion resistance is required. They are commonly used in the manufacture of jet and rocket engines, chemical processing equipment, and nuclear reactor components. Many commercial and cryogenic applications are now in service. These brazing filler metals are normally supplied as powders (Ref. 1). Recently, flexible nickel-based amorphous brazing foil has been developed, using rapid solidification technology (Refs. 2, 3, 4). Previously, these materials were mainly available only in powder or paste forms. The greatest advantage of this rapidly solidified nickel-based amorphous brazing foil is its flexibility (Ref. 4). This flexibility allows the foil to be used on curved joints. The foil also proved to be a more effective method of applying the brazing filler metal in joints having a large area.

Clad materials have been defined as those that have been metallurgically joined to a heat or corrosion resistant material. An example would be stainless steel or nickel-based heat resistant alloy bonded to mild steel, using either a rolling, explosive joining, chill casting to the surface of the container, or diffusion method. Clad materials are used for wide and/or large joining areas. Brazing, using a nickel-based brazing foil, has been an effective method for producing clad materials.

In this study we produced a simulated clad material by brazing the nickel-based heat resistant Alloy 600 to SM41B mild steel with various nickel-based brazing foils. We then studied the brazeability of the brazing foil for producing clad materials. In order to evaluate the brazeability of these foils, we had to determine the following:

1) The relationship between the shear strength and the brazing factor (Ref. 2).

KEY WORDS
Brazing
Nickel-Based Alloy
Brazing Filler Metal
Ni-Si-B Filler Metal
Ni-Cr-Fe-Si-B Alloys
Alloy 600
Intermetallics
Shear Strength
2) The relationship between the shear strength and the microstructure of the brazed joint (Ref. 3).

3) The influence of the interface reaction, including the migrations of the elements contained in the nickel-base brazing foil and base metal on the microstructure and the shear strength at the brazed joint.

This paper describes the results of a research program that addresses the above objectives.

Experimental Procedure

The chemical compositions of the four nickel-based brazing foils and two base metals used in this study are shown in Tables 1 and 2. In this study, the base metals were Alloy 600 and mild steel SM41B.

The joint area of the base metals was polished and washed with acetone before brazing. Brazing foil was placed between the Alloy 600 and steel, as shown in Fig. 1. Brazing was done in an electric resistance heated furnace in an argon gas atmosphere.

Brazing temperatures were 50°, 100°, and 150°C (90°, 180°, and 270°F) above the liquidus temperature of each brazing foil. In the case of BNI-2, the liquidus temperature was 1000°C (1832°F); so the brazing temperatures were 1050°, 1100°, and 1150°C (1922°, 2012°, and 2101°F). Brazing times were 10, 20, 30, and 60 minutes for each type of foil.

Braveability was measured by the mechanical properties, distribution of the elements and hardness in the brazed joint. The method used for obtaining the mechanical properties was the “Test Specimen and Method of Making Shear Test of Clad Plate” (ASTM A264) (Ref. 5). The distributions of the elements in the brazed joint and the base metal were determined by using a scanning electron microscope (SEM) and an electron probe micro-analyzer (EPMA) examination. The hardness distribution at the brazed joint was measured by the Vickers hardness tester. The load employed was 50 g and the holding time was 20 s.

Results and Discussion

Ni-Si-B System Brazing Foil

The shear strength of the specimen made with BNI-3 brazing foil was increased by increasing the brazing time, as shown in Fig. 2. For each of the three brazing temperatures, the maximum shear strength was reached in 60 minutes at the brazing temperature. The shear strength of the specimen made with Ni-Si-B brazing foil was increased by increasing the brazing time at 1110° and 1160°C (2030° and 2120°F), as shown in Fig. 3. The shear strength of the specimen brazed at 1060°C (1940°F) was only slightly influenced by the brazing time.

A typical microstructure of the BNI-3 joint brazed at 1090°C (1994°F) is shown in Fig. 4. The microstructure of the brazed joint consisted of the alpha nickel phase and the eutectic structure. The area of the eutectic microstructure in the brazed joint decreased with increased brazing time, as shown in Fig. 4. The microstructures of the brazed joints made with other brazing foils (BNI-1 and BNI-2) were very similar to these microstructures. However, in the case of Ni-Si-B, for all of the brazing conditions, the microstructures at the brazed joint consisted of alpha nickel solid solution only.

For all of the brazing conditions, the failure of the specimen, during the shear test, occurred in the brazed joint. When the eutectic structure remained in the brazed joint, the fracture occurred at the eutectic structure, as shown in Fig. 5. With the decreasing amount of eutectic structure in the brazed joint, the shear strength increased. When the eutectic structure in the brazed joint was removed by increasing the brazing time, the shear strength reached its maximum value. The eutectic structure, which influenced the shear strength, was a very hard phase, as illustrated in Fig. 6. It was concluded that the presence and quantity of the eutectic structure in the brazed joint reduces the shear strength.

In the case of Ni-Si-B, the eutectic structure was not present in any of the specimens brazed in this study. It appears that the elemental boron diffused from the brazing foil into the base metal, as the boron content in Ni-Si-B was less than that in BNI-3.

Table 1 — Chemical compositions of nickel base brazing foils.

<table>
<thead>
<tr>
<th>Chemical compositions (mass %)</th>
<th>Temperature (°C)</th>
<th>Temperature (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BNI-3</td>
<td>Ni</td>
<td>Cr</td>
</tr>
<tr>
<td>Bal.</td>
<td>4.5</td>
<td>3.2</td>
</tr>
<tr>
<td>Ni-Si-B</td>
<td>Bal.</td>
<td>7.3</td>
</tr>
<tr>
<td>BNI-1</td>
<td>13</td>
<td>4.2</td>
</tr>
<tr>
<td>BNI-2</td>
<td>7</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 2 — Chemical compositions of base metals

<table>
<thead>
<tr>
<th>Chemical compositions (mass %)</th>
<th>Temperature (°C)</th>
<th>Temperature (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alloy 600</td>
<td>C</td>
<td>Si</td>
</tr>
<tr>
<td>0.07</td>
<td>0.22</td>
<td>0.44</td>
</tr>
<tr>
<td>SM41B</td>
<td>0.06</td>
<td>0.15</td>
</tr>
</tbody>
</table>

The elemental distributions at the brazed joint made with Ni-Si-B are shown in Fig. 7. According to these elemental distributions, the brazed joint contained a very low concentration of boron. The fact that boron was not contained in the brazed joint and the eutectic structure was not observed in the brazed joint, shows there was complete diffusion of boron from the brazing foil to the base metal.

However, in the case of BNI-3, under similar brazing conditions, the eutectic structure was formed in the brazed joint. Figure 8 shows the concentration of chromium and nickel at the eutectic...
Fig. 2 — Effect of brazing time and brazing temperature on shear strength. Brazing foil is BNi-3.

Fig. 3 — Effect of brazing time and brazing temperature on shear strength. Brazing foil is Ni-Si-B.

Fig. 4 — Microstructures of cross-section at the brazed joint for brazing foil BNi-3 at brazing temperature 1090°C.
Alloy 600

Crack

(1) Brazing time: 10 min

Steel (SM41B)

(2) Brazing time: 60 min

Fig. 5 — Cross-sectional microstructure of the specimen made with BNi-3 during the shear test. Brazing temperature was 1090°C. A — Brazing time 10 min; B — brazing time 60 min.

Fig. 6 — Microhardness (Vickers) profile of the brazed joint made with BNi-3.

Alloy 600

Crack

Steel (SM41B)

Brazing time: 10 min

Brazing time: 60 min

100 μm

Fig. 7 — BSE image and elemental maps of Ni, Cr, Fe, Si and B at the brazed joint made with Ni-Si-B. Brazing temperature 1060°C, brazing time 10 min.
In the case of nickel-based filler metals, when brazing at lower temperatures and for short times at heat, the boron and/or silicon will not readily diffuse from the molten brazing filler metal into the base metal; however, some dissolution of the base metal does occur. When the composition of the boron and/or silicon in the molten brazing filler metal reaches equilibrium at the brazing temperature, the dissolution reaction of the solid base metal would stop. Diffusion of the boron and/or silicon from the molten brazing filler metal into the base metal would come next (Refs. 6, 7). Therefore, when the diffusion of boron and/or silicon from the brazing filler metal to the base metal was observed, the dissolution reaction had finished, and it appeared that the isothermal solidification had started.

Nickel, chromium and iron migrated rapidly during progression of the dissolution reaction, but this reaction is finished within a few minutes (Refs. 6, 7). After the dissolution reaction is complete, it appears that the isothermal solidification begins and the diffusion of nickel, chromium and iron in the base metal slows down. However, the boron rapidly diffuses into the base metal, and therefore, the eutectic structure disappears, and the elemental distribution of chromium becomes less uniform.

As mentioned earlier, the microstructure of the brazed joint is an indicator of the strength of the specimen. The diffusion of boron and chromium have the greatest impact on the microstructure of the brazed joint.

It was concluded that the eutectic structure was formed in the first minutes of brazing and that further diffusion of boron to the base metal improved the shear strength of the specimen. Thus, when the eutectic structure disappeared, the diffusion of chromium and/or iron into the brazed joint area improved the shear strength of the specimen.

Chromium and/or iron diffused more slowly in the base metal, and it appeared that increasing the chromium led to improvement of the shear strength. If the brazing foil contained chromium and/or iron originally, the shear strength of the specimen would be expected to improve. The other types of brazing foil containing chromium and iron are described below.

Ni-Cr-Fe-Si-B System Brazing Foils

The shear strength of the specimen made with BNi-1 brazing foil increased with increased brazing time, as shown in Fig. 9. When held at the brazing temperature for a period of 60 minutes, the shear strength reached maximum for the 1275°C (2327°F) and the 1225°C (2377°F) brazing temperatures. In the
case of BNi-2 brazing foil, the shear strength increased by increasing brazing time and temperature, as shown in Fig. 10. At the 1100°C (2012°F) and the 1150°C (2102°F) brazing temperatures, the shear strength increased with time at the brazing temperature and reached maximum at 60 minutes. At the 1050°C (1922°F) brazing temperature, the shear strength increased very slightly with increased brazing time.

The elemental distributions and typical cross-sectional microstructures at the brazed joint made with BNi-1 and BNi-2 are shown in Figs. 11 and 12. In the case of these two types of brazing foil, the cross-sectional microstructure resembled the alpha nickel phase and a eutectic structure similar to the microstructure of the brazed joint made with BNi-3. For specimens brazed under all different brazing conditions, the break in the specimen occurred in the brazed joint. If the eutectic structure was formed in the brazed joint, the break occurred in the eutectic structure similar to the brazed joint made with BNi-3.

The nickel, chromium and boron were concentrated in the eutectic structure. The chromium was concentrated in the alpha nickel phase as compared...
with distribution of the elemental chromium in the brazed joint made with BNi-3 and Ni-Si-B. The shear strength of the specimen made with BNi-1 and BNi-2 was greater than that made with BNi-3 and Ni-Si-B. Thus, it seems that the concentration of chromium in the alpha nickel phase improved the shear strength of the specimens made with BNi-1 and BNi-2.

Conclusions

In this study, the clad specimens were fabricated from nickel-based heat resistant Alloy 600 and SM41B mild steel and were brazed with four types of nickel-based brazing filler metals. The brazeability of these brazing filler metals was determined by the shear strength, the observation of the cross-sectional microstructure, the hardness distribution, and the elemental distribution. The following results were obtained:

1) The shear strength of the specimens made with BNi-1 and BNi-2 brazing foils containing chromium and iron was higher than clad specimens made with BNi-3 and Ni-Si-B brazing foils. Under all brazing conditions, the location of the failure during the shear test occurred in the brazed joint. If the eutectic structure remained in the brazed joint, the break occurred in the eutectic structure. The shear strength was increased by decreasing the amount of cross-sectional area of the eutectic structure at the brazed joint. The shear strength was increased to maximum by increasing the diffusion brazing time, which eliminated the eutectic structure in the brazed joint.

2) With the BNi-3 filler metal, the eutectic structure is formed in the first minutes of brazing. As time at the brazing temperature is increased, boron diffuses into the base metal, resulting in the elimination of the eutectic structure. Chromium and/or iron diffuse from the base metal into the brazed joint, thus assisting in increasing the joint strength with added time at brazing temperature.

References