Brazing Titanium in Air

This study shows titanium can be brazed in air if the appropriate fluxes and alloys are used

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Titanium is an important metal with many excellent properties: It has high specific strength, is relatively light, and exhibits good corrosion resistance. Based on these properties, titanium is now used in many aeronautical and space applications (Ref. 1), replacing stainless steel and nickel-based alloys. Brazing is an important joining method for many of these applications.

On the downside, titanium is difficult to join because it oxidizes rapidly. It is virtually impossible to solder. Additionally, until recently, all titanium brazing had to be done in a vacuum or an inert gas furnace. This caused problems to those who repair titanium eyeglass frames, who found it almost impossible to repair frames inexpensively.

Recently, it has been shown that titanium and its alloys can be successfully brazed in air using specially developed fluxes and the appropriate silver alloys (Refs. 2, 3). This includes brazing titanium to many metals and tungsten carbide. For many operators, the ability to braze titanium and its alloys in air is a game-changer, as they can now manufacture items at the bench using gas torches or induction heating — Fig. 1.

The ability to successfully braze titanium in air stems from the development of a special flux based on alkali-metal-halide-type formulations. The flux protects the titanium from oxidation up to 750°C, which is sufficiently high to melt the filler alloys and successfully braze the titanium. However, care must be taken at this elevated temperature because the ability of the flux to protect the titanium from oxidizing dissipates rapidly. Yet, if managed carefully, the flux creates the possibility of brazing titanium in air.

One example of brazing titanium in air involves the titanium eyeglass industry. When titanium frames are broken, a repair option that does not involve an expensive controlled atmosphere setup is desired. The specially developed flux permits rapid repair of these titanium glasses.

Using torch heating, brazing titanium in air is also used for making the difficult titanium-to-carbide connections found in knife blades. Another application involves using the same chemistry to make a titanium-to-carbide connection with induction heating — Fig. 2.

This article details a study that was undertaken to closely examine the effect of brazing titanium in air. Heating was conducted by torch, and scanning electron microscope (SEM) and energy dispersive spectroscopy (EDS) evalu-
tions were performed on the polished cross-sectioned samples. These images showed the structure and composition of the intermetallic compounds formed in the braze zone between the titanium and the filler metal alloy. The presence of an intermetallic compound and dendritic growth demonstrate that brazing was successful.

Experimental Method

The following details the experimental method used in this study. **Development of brazing flux for titanium alloys.** The typical fluoride-based fluxes used for other base metals are not successful in removing the oxides that occur during the brazing of titanium. Because titanium oxidizes very rapidly, it is important to have a flux that can effectively react with the titanium surface when brazing in air.

In developing a flux for titanium brazing, work began with the knowledge that both chlorides and fluorides were needed for brazing titanium in air. Early experiments began with a wide variety of inorganic halides in various combinations and ratios. As experiments continued, it was possible to deduce which halide salts showed the most promise and success in brazing. It was determined that the halide salts providing high-temperature capabilities were important for oxidative protection of titanium. In testing the fluxes, experiments were conducted on a range of alloys, including silver and aluminum alloys.

**Flux.** TBF-19 was used for this study. It is a water-based formula for torch brazing titanium and titanium-based alloys with an active temperature range of 720–815°C (Ref. 4).

**Metal.** Titanium Grade 5 (Ti-6Al-4V alloy) was utilized according to ASTM B265, Standard Specification for Titanium and Titanium Alloy Strip, Sheet, and Plate.

**Brazing alloy.** BAg-34 containing 38Ag-32Cu28Zn-2Sn wt.-% (free-flowing) for ferrous alloys, nickel, copper, and their alloys and combinations was utilized according to American Welding Society ASME/AS1.8:2011, Specification for Filler Metals for Brazing and Braze Welding. The tin content in the alloy improves wetting of tungsten carbide, stainless steel, and other difficult-to-braze metals (Ref. 5).

**Torch heat.** This study employed methylacetylene-propadiene propane (MAPP) gas, a stabilized fuel gas mixture (Ref. 6).

**Sample preparation.** Each sample was prepared using titanium and BAg-34 braze alloy heated to fusion by the MAPP gas. The samples were then mounted in epoxy, cross-sectioned, and polished. The SEM and EDS evaluations were done on the polished cross-sectioned samples.

**SEM.** SEM was equipped with high-magnification, backscattering, and

**Table 1 — Combined EDS Analyses Results (EDS Areas 1-4)**

<table>
<thead>
<tr>
<th>Spectrum</th>
<th>Al</th>
<th>Ti</th>
<th>V</th>
<th>Cu</th>
<th>Zn</th>
<th>Ag</th>
<th>Sn</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDS Area 1</td>
<td>74.81</td>
<td>91.040</td>
<td>1.479</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>EDS Area 2</td>
<td>4.307</td>
<td>28.301</td>
<td>0.846</td>
<td>46.080</td>
<td>19.380</td>
<td>2176</td>
<td>-</td>
</tr>
<tr>
<td>EDS Area 3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>26.566</td>
<td>23.680</td>
<td>46.084</td>
<td>-</td>
</tr>
<tr>
<td>Mean</td>
<td>5.894</td>
<td>48.359</td>
<td>1.23</td>
<td>23.122</td>
<td>17.758</td>
<td>22.719</td>
<td>37918</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>2.244</td>
<td>38.762</td>
<td>0.377</td>
<td>16.663</td>
<td>6.665</td>
<td>24.383</td>
<td>0.000</td>
</tr>
<tr>
<td>Min.</td>
<td>4.307</td>
<td>21.735</td>
<td>0.846</td>
<td>13.829</td>
<td>10.203</td>
<td>2176</td>
<td>0.000</td>
</tr>
<tr>
<td>Max.</td>
<td>74.81</td>
<td>91.040</td>
<td>1.479</td>
<td>46.080</td>
<td>23.680</td>
<td>46.084</td>
<td>0.000</td>
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**June 2020 / Welding Journal**
elemental color mapping capabilities.

EDS. EDS was used to detect individual elemental wavelengths and their relative abundance.

Results and Discussion

In the SEM photo of the cross section (Fig. 3) using the TiBF-19 flux, the BAg-34 alloy (bottom) had been brazed to titanium (top). What can be seen in Fig. 3 is the interaction of the titanium to the braze alloy at the intersection of the two alloys, causing an intermetallic layer to be formed. Figure 3 also shows there was a secondary interaction in the body of the braze alloy beyond the initial intermetallic zone, which resulted in the creation of a star-shaped, dendritic-like formation.

The SEM analysis was done on the titanium layer (Fig. 4), the initial intermetallic zone (Fig. 5), the area between the intermetallic zone and the dendritic structure (Fig. 6), and the star-shaped dendritic structure (Fig. 7). A summary of the EDS analysis results is shown in Table 1. For a complete picture of what was occurring elementally, color mapping was done for each element (Fig. 8), which shows where each evaluated element appeared in the cross section and illustrates how each element contributed to the structure seen.

Based on the analysis on titanium-to-braze alloy testing, the following can be stated:

1. There are two different inter-
metallic areas to consider; one right at the braze alloy interface and one from the dendritic growth in the body of the braze alloy associated with the titanium dissolution.

2. The primary intermetallic area formed between the braze alloy and the titanium appeared to be a copper-titanium compound.

3. In the second intermetallic area, there was a dendritic area high in titanium and tin.

Conclusions

The ability to make a brazed connection to titanium in air is a great improvement for the ease of titanium metalworking. The test results show there was an intermetallic layer created between the braze alloy and the titanium metal, which proves the validity of this brazed connection.

On the titanium-to-brazed alloy connection (Table 1), the percentage of titanium to copper in the intermetallic zone was likely in the form of the titanium-copper compound Ti3Cu4, based on the ratio of titanium to copper in the predominant intermetallic phase next to the titanium border (Ref. 7).

The dendritic growth of the titanium-tin alloy in the braze alloy phase appeared to be the result of excess dissolved titanium being available after the titanium-copper had formed its intermetallic compound. The presence of dissolved titanium combined with tin form the dendritic structure when insufficient copper is present as a binding element.

Acknowledgments

The authors would like to thank Andy Schmitt, dispensing optician, Kisilek Eye Center; Darrel Christian and Alyss Morton of TitanX for the preparation of the cross sections; Peter Bush, director of the University of Buffalo’s South Campus Instrument Center, for the SEM and EDS work; and Alexander Shapiro of Titanium Brazing Inc.; and Alex Greenspan of Braze Solutions for their assistance.

References


