BRAZING Q&A

Q: As my aerospace brazing business continues to expand, I’m considering adding aluminum brazing to my growing mix of vacuum-brazed components. I have a number of large vacuum furnaces in my brazing shops that we currently use for high-temperature brazing of stainless steel and superalloys (using nickel-based filler metals and some gold-nickel alloys), but they are not being fully utilized, and one of my sales engineers asked if we might want to consider utilizing the extra time in many of those furnaces by adding in aluminum brazing to our mix. Is that a good idea? Do you have any recommendations?

A: There are a number of reasons why that is a very bad idea, but I will briefly review just two of the more obvious ones below.

Temperature Control

Shown in Fig. 1 is a typical vacuum furnace used for high-temperature aerospace brazing. Notice there are a number of heating elements (the rings of sheet metal around the inside of the furnace chamber) inside the furnace “hot zone,” but there are no heating elements on the front door, or on the back wall of the furnace. The rings inside that hot zone are typically constructed of moly alloys, are electrically heated, and can often bring the furnaces to temperatures in excess of 2400°F (1300°C).

Temperature uniformity in the chamber can be controlled by varying the amount of power sent to each of those heating elements in the hot zone. In such a case, each heating element might then be called a separate heating zone. Sometimes more than one heating element might be controlled together, thus creating a multiplex element zone of heat control. Please note that the more heat zones a furnace can provide, the better the potential for refined temperature control and temperature uniformity in that furnace chamber.

For standard vacuum furnaces operating up to about a 2400°F (1300°C) maximum, control of the actual temperature in the hot zone may be limited to about ±25°F (i.e., about ±15°C), which means a maximum temperature differential of up to about 50°F (30°C) within that work zone.

Now, take a look at the chart in Fig. 2, comparing some aluminum base metals on the left side of the chart...
with the aluminum brazing filler metals (BFMs) on the right side of the chart.

Notice the “approximate solidus temperature” solid lines on the left side of Fig. 2 just above the suggested brazing range for each of those base metals. It is interesting to see that according to this chart, some of these aluminum materials should be brazed at temperatures that are only about 10°–50°F (5°–30°C) below the actual melting points (solidus temps) of those base metals. The reason for this is that, unfortunately, the aluminum-based BFMs available for this kind of work can only melt and flow at temperatures very close to the melting points (solidus temperatures) of the base metals. (Note: Research work continues in an effort to develop effective aluminum BFMs that operate at lower temperatures.)

Since aluminum brazing in a vacuum furnace can therefore take place only a few degrees below the melting point of the base metals, furnaces that would be used for this kind of work must be capable of very tight temperature controls, much tighter than that which can be achieved in standard high-temperature aerospace-type vacuum furnaces.

To achieve the very close temperature control needed for aluminum brazing, aluminum brazing vacuum...
furnaces typically have many more controllable heating zones than a typical aerospace vacuum furnace. Not only might there be more heating elements around the inside wall of the furnace, but additional heating elements are typically added both on the front door of the furnace and on the back wall of the furnace (the back wall can often be opened as well), as shown in Fig. 3.

With all these closely controlled heating zones available, an aluminum vacuum brazing furnace can typically control temperatures to about ± 5–10°F (i.e., about ± 2–5°C) when loaded with parts.

Therefore, it is very important for everyone to realize that brazing of aluminum requires extremely tight temperature control to allow the aluminum BFM to melt and flow without also melting the aluminum base metal being joined. Attempting to use the "extra time" available in your high-temperature aerospace furnaces for aluminum brazing might indeed give you lots of extra time that you'll need to replace the one you destroyed by trying to braze aluminum parts in it. Be careful!

**Furnace Contamination**

Aluminum brazing in vacuum furnaces typically also involves the need to introduce magnesium (Mg) into the vacuum chamber to getter any oxygen present in the chamber during brazing operations. Magnesium is typically added into either the BFM itself, or into the aluminum base metal being brazed. Sometimes it is added as separate Mg powder in a little crucible set inside the furnace. The purpose of the Mg is to vaporize during heating — usually in the area of about 800°–850°F (425°–460°C) — so that this Mg vapor will react with any available oxygen in the chamber to keep the oxygen from reacting with the aluminum to form a stable, continuous layer of aluminum oxide on the surface of the aluminum parts being brazed.

Aluminum always has a layer of oxide on its surface. But, when aluminum is heated, the aluminum base metal expands almost four times faster than the aluminum oxide layer on its surface. This causes the oxide layer to fracture and expose the pure, clean aluminum below it, which the molten BFM can readily alloy with. Any oxygen in the furnace wants to react to those spots to "heal" those cracks in order to reform a continuous layer of oxide, and the Mg absorbs that oxygen preventing it from healing those cracks so that the BFM can get into those cracks instead.

Figure 4 shows a photo of the typical Mg-oxide layer on a pin, taken from a vacuum chamber after aluminum brazing. Note that the Mg condenses as a powder on parts, furnace walls, and more, and is also highly py-
ophobic. Additionally, the aluminum itself can outgas, condensing on your furnace walls, in addition to the Mg problem previously mentioned.

This outgassing of Al and Mg could be a major issue for aerospace furnaces used for stainless steels since any contamination from aluminum alloys can totally ruin subsequent high-temperature furnace runs for stainless steels and superalloys.

It is important to note that a number of brazing shops have learned the hard way that trying to remove any Al and Mg contaminants is not only extremely costly and difficult, but a number of such vacuum furnaces have been ruined and scrapped by such attempts at aluminum brazing.

As an example, someone told me about a company who made the mistake of trying to braze a titanium alloy part in a vacuum furnace, using an aluminum-based BFM, indicating that they were not concerned by the lack of overall temperature control of their furnace, since the melting point of the aluminum BFM was well below the melting temperature of the titanium alloy being joined. However, the Al and Mg that was outgassing from the BFM, and from some of the Mg in the BFM, ruined their furnace hot zone, aluminumized the insulators, and put a Mg-oxide coating on the furnace walls that continually outgassed whenever the furnace was used, thus rendering the aerospace furnace useless for regular aerospace brazing. It was a costly mistake, but they never repeated it again.

Conclusion

If you desire to do any kind of aluminum brazing, whether it’s to join aluminum base metals together or other metals such as titanium, I strongly recommend you never use a regular aerospace type vacuum furnace for that purpose, but instead, use only a vacuum furnace built specifically and only for aluminum brazing.

As shown in Fig. 2, you should only use a vacuum furnace specifically built for brazing aluminum if your intent is to add aluminum brazing to your brazing shop capability. Never, never braze aluminum parts in a regular high-temperature aerospace furnace.

References


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