HOW TO IDENTIFY BRAZING FAILURES

Robert Peaslee
Wall Colmonoy Corp.
Madison Heights, Michigan

For many years now, I seem to have baffled the brazing community with the ability to identify the cause, or multiple causes, associated with brazing failures. Fortunately, I have a varied background in many industrial disciplines and more than sixty years of hands-on experience to draw upon. There is no “secret” to this perceived talent; the key is to be observant.

If a process fails and a part is scrapped, I will sift through the trash to retrieve it and find out what it is telling us. Similar to a detective following up clues in a case, or a doctor diagnosing an illness according to the symptoms, I have made a practice of noticing the most minute variations, or “footprints” as I like to refer to them. The cause is often right in front of us; we simply need to know where to look.

My process for identifying the cause of brazing problems begins with careful examination of the brazement, which will usually reveal the variations or “footprints.” Even the slightest variation is significant. This also applies to assemblies that appear to have been brazed successfully, because the slightest variation could indicate that the brazing process is on the threshold of failure.

This brief excerpt focuses on the footprints observed when the brazing atmosphere is not quite right.

Atmosphere quality

When any brazing process goes awry, the first and most critical variable to consider is the quality of the atmosphere. The problem may stem from the type of atmosphere and whether it is suitable for the base metals being brazed; or from the level of partial pressure of oxygen in the atmosphere (sometimes measured as dew point in gas atmosphere furnaces); or a combination of these factors. Atmosphere quality is the variable most often overlooked and is the least controlled.

There is a common rule in brazing that applies to many cases involving atmosphere quality: The tolerable amount of contaminants in a given atmosphere is directly proportional to the heating rate. Thus, the faster a brazement is heated, the more contaminants or poorer atmosphere quality that can be tolerated with the same brazing results. Conversely, the longer the heating time, the better is the atmosphere quality required.

Discoloration footprints

A common footprint associated with poor atmosphere quality is discoloration of the brazed part. Discoloration may indicate a leak in the argon or nitrogen line during the vacuum furnace cooling cycle. Discoloration accompanied by improper brazing filler metal flow may indicate a leak in the vacuum furnace during the heating cycle prior to reaching brazing temperature.

In such cases, discoloration and improper brazing filler metal flow are caused by an abnormal partial pressure of oxygen in the furnace. In general, partial pressure of oxygen in the brazing atmosphere is the primary controlling factor that determines proper wetting of brazing filler metal across base metal surfaces and through the joint.

A break in discoloration, often appearing as bright shiny stripes on a brazed part, is another footprint. This may indicate that the part was on a flat surface, such as a fixture, which prevented oxygen molecules from affecting the base metal surface and causing discoloration during cooling. The variations in base metal discoloration can include:

- **Discoloration**
- **Degree of filler metal residue** (unmelted)
- **Unusual formations** (lumps, blisters, glass-like beads, etc.)
- **Distortion**
- **Improper brazing filler metal wetting and flow**
- **Porosity**
- **Cracking**
- **Voids**
- **Weak joints**
- **Etched surfaces** (by furnace atmosphere or other sources)
- **Base metal erosion**

Dedicate different levels of atmosphere quality: gold indicates a higher than normal partial pressure of oxygen; brown indicates an even higher level; and blue indicates a still higher level of oxygen.

A classic footprint indicating a leak in a gas atmosphere piping system is decreasing dew point readings when the atmosphere flow into the furnace is increased. With high-purity gases such as argon, nitrogen, and hydrogen, partial pressure of oxygen, including water, is so low in the gases and so high outside the piping system that the oxygen and moisture will counterflow the gases in the leak and enter the piping system, thus contaminating the atmosphere.

Colored beads and residue

Another footprint indicating poor atmosphere quality is the formation of glass-like beads on parts that have been brazed in a gas atmosphere furnace. These formations indicate oxidation caused by an excessively high partial pressure of oxygen in the atmosphere. For example, certain elements such as boron will oxidize when the partial pressure of oxygen is too high in the gas atmosphere. The partial pressure of oxygen may be indicated by the color of the glass-like bead formations and other residues.

- **Clear beads:** Clear glass-like beads indicate that only the boron in the brazing filler metal has oxidized.
- **White beads:** A white milky appearance indicates that the beads have picked up moisture, and have changed from boron oxide to boric acid when exposed to air.
- **Green beads:** When beads have a green color, a higher partial pressure of oxygen is present, which causes the boron oxide to absorb the chromium oxide from the brazing filler metal that has oxidized to a lower valence (level of oxygen), thus forming green chromium-oxide glass beads.
- **Black beads:** Black signifies a still higher partial pressure of oxygen, causing the boron and chromium in the brazing filler metal to oxidize, and the chromium to oxidize to an even higher valence, thus forming the black chromium-boron oxide bead.
- **Black residue:** Poor atmosphere quality may also be the culprit when a black residue is observed on a nickel brazing filler metal containing phosphorus.

Although brazing with such a material in an atmosphere with higher than normal partial pressure of oxygen, the phosphorus partially oxidizes to a different valence, producing a modified nickel phosphide residue. By using a vacuum atmosphere of 10⁻³ to 10⁻⁵ torr (0.133 to 0.001 Pa), or a dew point below -60°F (-51°C) in a gas atmosphere, the black residue can be prevented. The critical temperature range is between 1000 and 1700°F (538 and 927°C), where these atmospheres are oxidizing to elements such as phosphorus, chromium, aluminum, titanium and so forth.

- **White powder:** When white powder residue forms on the cold section of a vacuum-purged hydrogen retort or a vacuum furnace, and boron-containing nickel brazing filler metals are being used, poor atmosphere quality may be the cause. The water-soluble powder residue that collects on the cold area of the furnace indicates that the boron has oxidized from the brazing filler metal and the atmosphere was poor. The more white powder present, the worse the atmosphere quality.

Good atmosphere quality is crucial to the success of the brazing process, and although this variable is the most easily controlled, it is usually the least considered when problems arise. Whether the footprints are discoloration, poor brazing filler metal wetting and flow, or unusual formations on base metal surfaces, poor atmosphere quality is often to blame and should be the first component examined in the brazing process.

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**Elements of the brazing process**

For any brazing process to be successful, two conditions must be met: first, the brazing filler metal must wet the base metal; second, the brazing filler metal must flow completely through the joint by capillary action. The most common variables that affect these conditions, and may lead to one or several of the footprints listed, are as follows:

- Atmosphere quality
- Readily oxidizable elements in the base metal
- Type of atmosphere
- Temperature differential
- Fixturing
- Surface preparation and cleanliness
- Joint clearance
- Quantity of brazing filler metal
- Type of brazing filler metal

All of these variables should be considered together, because it is not unusual to have several factors that contribute to a problem. As a result, many different footprints may be observed.

Many people discount the complexity and sophistication of the brazing process. They assume that it can be relegated to the back corner of their shop where it will take care of itself. I developed a chart in to show that brazing is indeed a very complex process with many variables that require engineering consideration. The five elements critical to success of the brazing process include Design, Base materials, Filler metals, Source of heat, and Protective covers.

(These five elements are detailed in a large table in Mr. Peaslee’s book.) The table shown here represents the first element of the process, Design considerations.

**Service environment considerations for braze joint design**

<table>
<thead>
<tr>
<th>Stress</th>
<th>Corrosion</th>
<th>Fixture type</th>
<th>Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level; constant; vibratory; shear; thermal.</td>
<td>Atmospheric; galvanic; thermal; stress; electrolytic; crevice.</td>
<td>No fixture best; self-jigging; press fit; tack welding.</td>
<td>Carbon-graphite; molybdenum; Alloy 600; AISI 330 SS; AISI 304 SS; carbon steel; ceramics.</td>
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*In addition to operating temperature*

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