Essential Considerations for Quality Braze Joints

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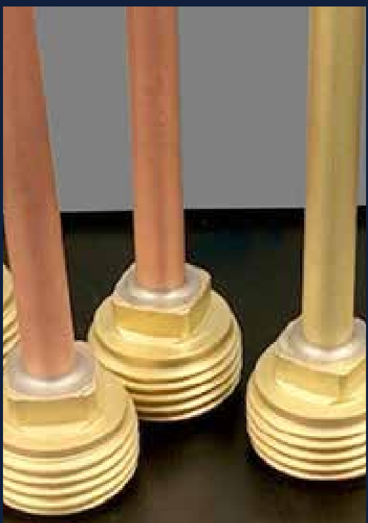
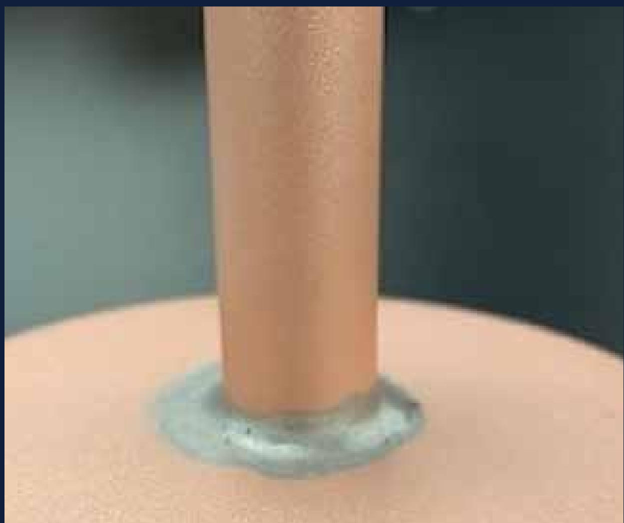
INDUCTION HEATING SOLUTIONS
an inTEST Company





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» To braze or not to braze: Essential considerations for quality braze joints

Metal joining with brazing is a commonly used technique in the manufacturing industry. Not only does this process produce parts that are stronger than the parent material, it also simplifies the manufacturing process. A number of complex parts can be made easily and repeatedly by combining more simply designed parts. Brazing can be used to join similar metals as well as dissimilar metals. Brazing is used in a plethora of industries including medical, aerospace, automotive and food.

The process of brazing involves the joining of two or more metal parts by heating them and using a third metal (braze alloy) which melts between them. It is important to have both parts reach the required brazing temperature at the same time. In lieu of this, the braze alloy tends to melt and stick to the part that is hotter and does not adhere well to the colder part. This produces what is commonly known as a ‘cold joint.’

Induction heating is a popular method for heating metal parts for brazing. A typical induction heating system is made up of an induction heating power supply, matching circuit and an induction heating coil. The induction heating coil is made of a water-cooled copper tube that has a high frequency alternating current flowing through it. This alternating current in the induction coil creates an intense magnetic field near the copper. The magnetic field produces an alternating current (eddy current) in the metal part placed in its vicinity. The eddy currents flow against the resistivity of the metal and produce heat. Induction heating is commonly used because of its speed, accuracy, repeatability and efficiency.

» Capillary Action

The basic principle of brazing is the flow of the braze alloy due to capillary action. Capillary flow is the ability of a liquid to flow in a narrow gap against traditional forces like gravity. The force of the capillary action is the same as the wicking of paint in between the bristles of a brush, or in induction brazing the wicking of the braze alloy between the two surfaces of the joint. The success of capillary action is a function of the surface tension of the liquid and the gap between the two surfaces. As the braze alloy melts during the heating cycle, the molten alloy is drawn through the joint due to this phenomenon. It is typically recommended to have a clearance joint of 0.002 to 0.004 thousandths of an inch for good capillary action for silver braze alloys.

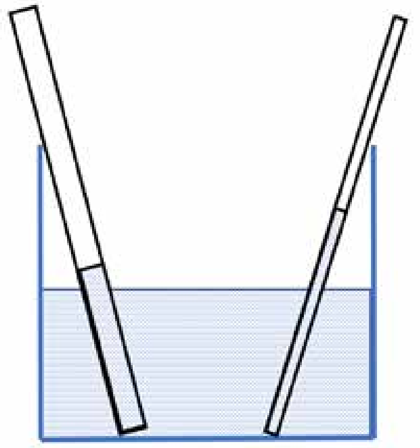

Figure 1: Liquid rise in different diameter capillary tubes due to surface tension.

Figure 2: Two parts heated in a water-cooled copper induction coil.

Figure 3: Open "U" shaped induction coil heating a steel tube and brass fitting for brazing.

Figure 4: Flow of braze alloy all around the circumference of the joint due to capillary action.

Figure 5: Stainless parts that are induction brazed.

Braze Alloys

A number of different braze alloys are available depending on the metals to be joined and the temperature required. Lower melting point braze alloys (1100-1400 °F/593-760 °C) are typically silver and copper alloys with the amount of silver varying from 50-20% in the mix. Higher temperature silver alloys typically have a higher percentage of copper. Even higher melting alloys are made of nickel and other metals and are popular in the aerospace industry. Steel to steel brazing often employs pure copper (melting point 1970 °F/1077 °C) as the brazing material because of the ability of the copper molecules to penetrate and fill extremely narrow gaps between press fitted steel parts. It goes without saying that silver-free brazing alloys are cheaper but require higher brazing temperatures to make the joint. Often this leads to loss of material properties and weakening of the finished parts.

Braze alloys are available in wire, strip or paste formulations. The selection is dependent on the design of the joint. In a number of induction braze applications, the use of braze preforms allows for uniform braze between joints. Selection of the braze wire diameter is determined by the amount of braze alloy needed and the frequency of operation of the induction system. Smaller wire diameters with multiple loops are favored in high frequency induction applications. This prevents the wire from heating directly in the induction field and prevents cold joints.

Figure 6: Various braze forms; from top to bottom, paste, wire and shims.

Figure 7: Carbide and steel parts along with three braze wire preforms.

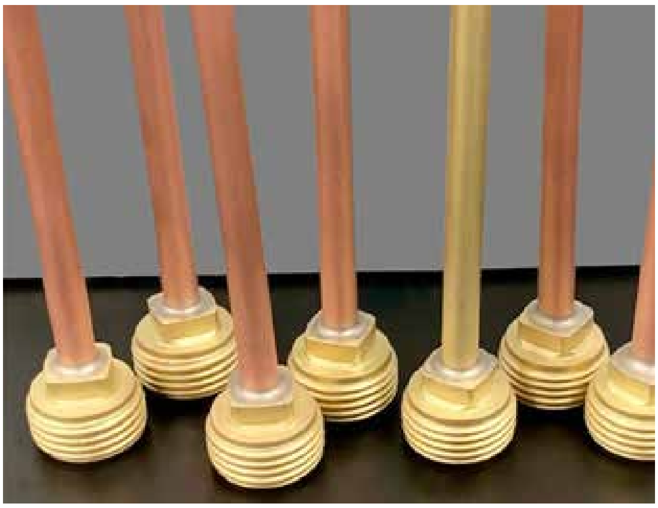

Figure 8: Copper and brass joints using braze wire preforms.

Figure 9: Brazing of carbide cutters and steel bases using braze shim preforms.

Eutectics

Brazing materials are alloys of two or more metals. The dominant metals in the braze alloys typically determine the melting temperature of the alloy. However, when these metals are mixed in particular ratios the combination typically melts at a temperature that is much lower than the alloying metals. The mixture is called a Eutectic. As an example, a silver copper eutectic will melt at 1400 °F (760 °C), while Silver and copper will typically melt at 1763 °F (962 °C) and 1984 °F (1084 °C) respectively. Copper, brass and steels can be joined together using this phenomenon at much lower temperatures than their actual melting points, thus preserving their mechanical properties. The finished joints are however typically as strong if not stronger than the parent metals since the joining compound (braze) has a good percentage of the parent material!

Another common eutectic that most people are familiar with is the mixture of Sodium Chloride (common salt) and water. The mixture lowers the freezing point of the water to -21.2 °C instead of being 0 °C. That is why salt is spread on roads to prevent them from freezing in winters. Another common use of this is in old fashioned ice cream makers where salt is used to lower the temperature to solidify the cream.

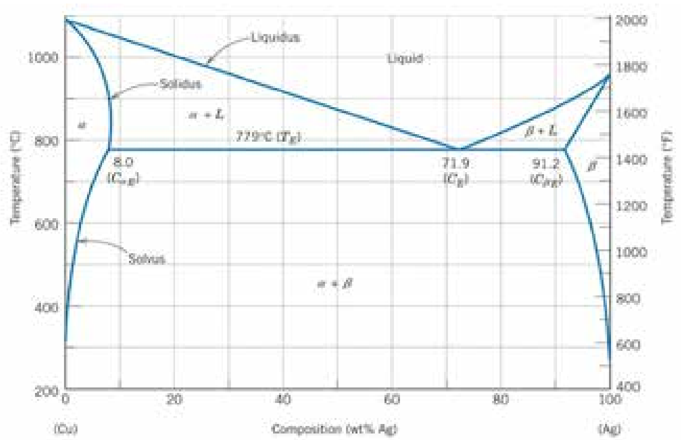

Figure 10: Copper and Silver Eutectic phase diagram.

Fixturing

Holding of the parts during the induction heating process is an art and a science all by itself. It's important for the holding devices to be capable of withstanding multiple heat cycles without deteriorating. The holding device should also not become a heat sink, robbing the heat from the acual parts being heated. In some applications the fixture is what is heated because the parts are so small that it is impractical to heat them directly. There are number of different options available to a manufacturing engineer when it comes to picking the material for the fixture. Titanium metal, ceramics or even graphite are used for holding fixture design as the molten braze alloy will not stick to these materials. In some applications, oxidised metals are used as the braze alloy and they'll not stick or flow over the oxides.

Figure 11: Flat carbides to steel brazed using induction heating.

Fluxes

Flux in a brazing process is an add-on paste or liquid that is applied to the joint area for better flow of the braze alloy. Fluxes are inert salts and do not interfere with the quality of the brazing process. The purpose of the flux is to provide a shield to the joint area so that the metal surfaces being heated do not oxidize. Braze alloy will typically not flow on oxidized surfaces and therefore it is important to keep the joint surfaces clean during the brazing cycle. Fluxes are essential catalysts that simplify the brazing process. Induction brazing requires the use of a flux to prevent the oxidation of the surfaces. In a number of induction brazing processes parts are prepared by drying the flux on the joint area so as to prevent unnecessary runoff away from the area of interest.

Figure 12: Heating of steel assemblies with white flux at the joint, shielding the braze wire pre-form and the part.

Figure 13: Finished brazed samples with minimal run-off of the braze to the outer diameter of the part.

Braze Fillets

Appearance and the size of the braze fillets has been a topic of considerable debate for some time. While a good visible braze fillet is reassuring that the braze alloy has flowed, the fillet itself does little to improve the strength of the braze joint. The strength of the braze joint is obtained from the lap joint area between the parts being joined, however the appearance of a good braze fillet may act as a simple quality control check for the brazing process. This does come at an elevated cost as the braze alloy is not necessarily inexpensive.

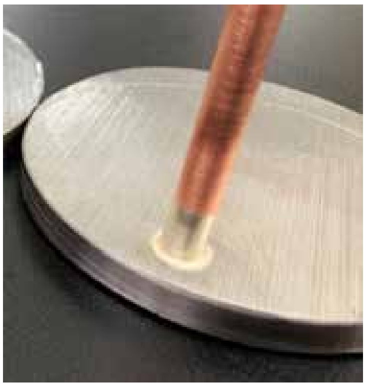

Figure 14: Braze fillet on a joint between the copper lid and tube

Figure 15: Braze joint between two steel rods. The fillet is an easy visual indication of the braze flow.

Figure 16: Braze joint between steel tube and brass fitting. The joints would benefit from a braze stop off in the brass threads to prevent the overflow of braze alloy.

Figure 17: Braze joint between steel disk and copper tube.

Braze Stop Off

In a number of brazing applications it is difficult to rely just on the capillary action to limit the flow of braze alloy to the joint area. It is often exasperated by the fact that the braze alloy flows towards the heat source, pulling it away from the joint. A few brazing applications can benefit from the use of a braze stop-off compound. It is a special material that can be painted on surfaces and restricts the flow of the braze alloy over the painted surface, thus limiting the flow for the braze in unwanted areas. A common braze stop off is calcium carbonate as it is resistant to high temperatures up to 1500-1600° F (816-871° C).

Figure 18: Braze joint between steel tube and brass fitting. The joints would benefit from a braze stop off in the brass threads to prevent the overflow of braze alloy.

Voids

Voids in braze joints are undesirable. They are also unpredictable and result in quality problems. They reduce the strength of the brazed parts. Often leaks in the braze joints are a result of the voids in the braze joints. The following are common practices for the elimination of voids in braze joints:

- Inadequate time at the brazing temperature for the braze alloy to flow and wick around due to capillary action, some processes require a soak at temperature to allow for the braze to flow.
- Improper cleaning of the parts before the brazing process. Any residues, oils or impurities from previous manufacturing steps can hinder the flow of the braze resulting in improper flow.
- Using the wrong flux or too little flux during the setup process.
- Improper joint clearance resulting in the loss of capillary force that pulls the liquid braze through the joint.
- Inadequate control of the brazing temperature; too hot will separate the braze alloy into its individual components, which have different flow characteristics.
- Not having a repeatable heating source, induction or otherwise.

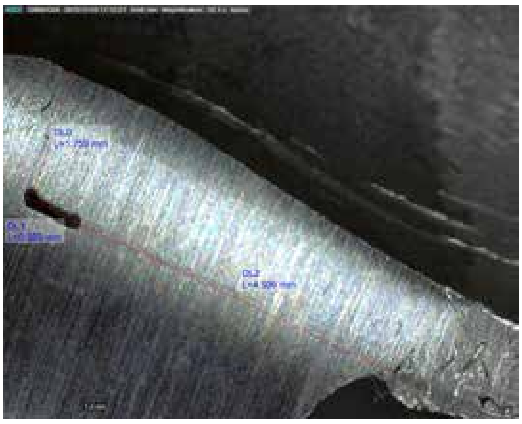

Figure 19: Brazed aluminum parts showing voids in the joint.

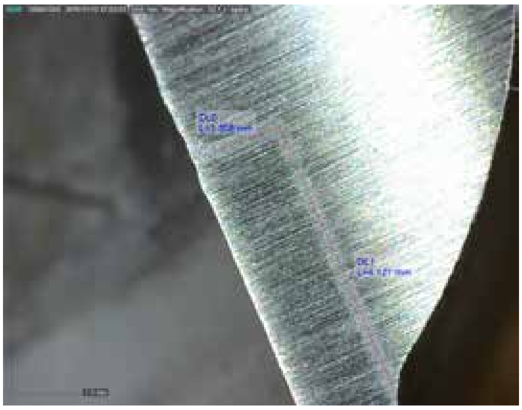

Figure 20: Brazed aluminum parts after careful attention to process details, shows no voids.

>> Inert Atmospheres

A number of applications, especially in the aerospace and automotive markets, require temperatures in the vicinity of 2000 °F (1093 °C). Generic fluxes do not work at these elevated temperatures. In order to protect the oxidation of the metal at these elevated temperatures, vacuum or other inert gas environments are needed. Typical inert gasses include cracked ammonia, nitrogen or argon. Other gasses may also be used for specialized applications.

Figure 21: Oxidation of steel parts when heated to 1900-2000 °F (1037-1093 °C) in air. An inert atmosphere is required to prevent this oxidation and facilitate the flow of the braze alloy.

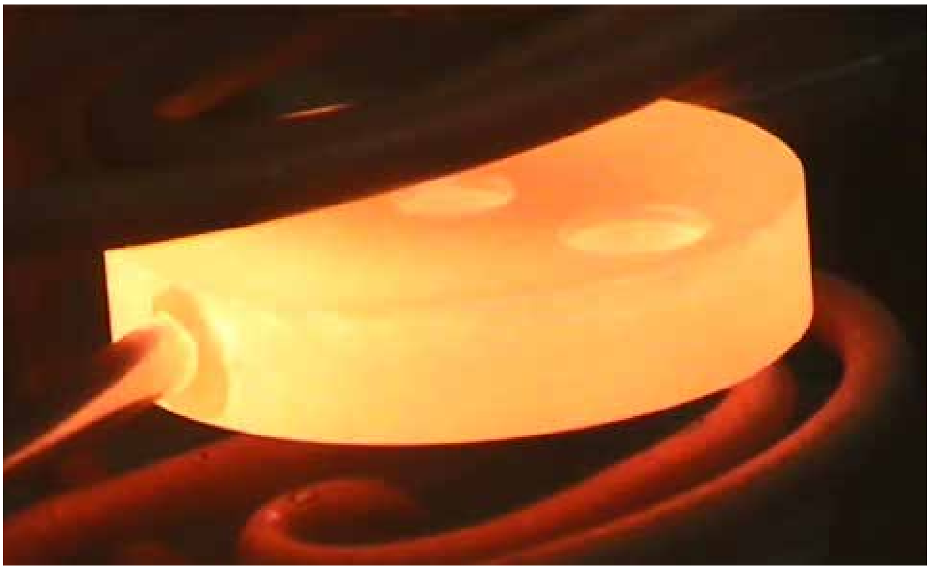

Figure 22: Steel parts being heated with copper braze alloy in an inert atmosphere. Notice the absence of oxidation on the steel.

Brazing is an essential manufacturing process allowing complex parts to be made by joining simpler part geometries. As you can see, there are a number of factors that influence the brazing process. Not all points considered in this paper may need to be considered for all processes. Induction heating offers the advantage of a repeatable, reliable and controllable process, which makes it popular in manufacturing.

Ambrell Power Supplies for Brazing

Ambrell manufactures a wide range of power supplies, both low and high power for an array of applications. For brazing, the EASYHEAT (1-10 kW) and the low power end of the EKOHEAT (10-15 kW) product lines are most popular.

Ambrell power supplies have movable workheads so the coil can be placed a distance from the power supply, a high power factor to ensure efficient heating, significant versatility with multiple capacitor and tap configurations, and repeatable, reliable heating with agile frequency tuning. Additionally, systems are compact and easy-to-integrate into manufacturing processes. Systems are manufactured at Ambrell's ISO 9001:2015 certified facility at its headquarters in Rochester, NY USA.

Complimentary Applications Testing

You can send parts to Ambrell's Applications Laboratory for a free half-day of testing. Testing is recorded and parts are sent back to you for inspection. Additionally, you are welcome to visit during testing to see induction brazing live.

After testing, you will receive a tailored system recommendation. The recommendation will be based on your process requirements, including process time, cycle time and temperature.

Brazing is a common application at Ambrell. So take advantage of that expertise and send in your parts for risk-free applications testing today.

About Ambrell

Founded in 1986, Ambrell Corporation, an inTEST Company, is a global leader in the induction heating market. We are renowned for our application knowledge and engineering expertise. In addition, our exceptional product quality and outstanding service and support are at the core of our commitment to provide a superior customer experience.

We are headquartered in the United States with additional operations in Europe including the United Kingdom and the Netherlands. All Ambrell products are designed, engineered and built at our manufacturing plant in the United States, which is an ISO 9001-certified facility. Over the last three decades we have expanded our global reach through an extensive distribution and OEM network, and today we have more than 15,000 systems installed in over 50 countries.

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