Technical demands made in production and assembly equipment are leading manufacturers of brazing systems to develop new technical innovations to improve productivity and quality. The most pronounced new trend in brazing technology is controlled atmosphere induction brazing, due to its cleanliness in production and superior finished appearance.

Principles of Brazing and Soldering

Brazing and soldering are processes for joining similar or dissimilar materials using a compatible filler material. Filler metals include lead, tin, copper, silver, nickel, and their alloys. Only the alloy melts and solidifies during these processes to join the workpiece base materials, entering the joint by capillary action. Soldering processes are conducted below 840°F while brazing applications are conducted at temperatures above 840°F and up to 2100°F.

The success of these processes depends upon the assembly’s design, clearance between the surfaces to be joined, cleanliness, process control, and the correct selection of equipment needed to perform a repeatable process.

Cleanliness is ordinarily obtained by introducing a flux, which covers and dissolves dirt or oxides displacing them from the braze joint. New techniques allow these operations to be conducted in a controlled atmosphere with a blanket of inert gas or combination of inert/active gases to shield the operation and eliminate the need for a flux. These methods have been proven on a wide variety of material and part configurations replacing or complementing atmosphere furnace technology with a just-in-time single-piece flow process.

Brazing Filler Metals

Brazing filler metals can come in a variety of forms, shapes, sizes, and alloys depending on their intended use. Ribbon, preformed rings, paste, wire, and preformed washers are just a few of the shapes and forms alloys can be found.

The decision to use a particular alloy and/or shape is largely dependent on the base materials to be joined.
placement during processing, and the service environment for which the final product is intended.

Clearance Affects Strength

The clearance between the faying surfaces to be joined determines the amount of braze alloy, capillary action/penetration of the alloy, and subsequently the strength of the finished joint. The best fitup condition for conventional silver brazing applications are 0.002 to 0.005 in. total clearance — Fig. 1. Aluminum typically is 0.004 to 0.006 in. Larger clearances up to 0.015 in. usually lack sufficient capillary action for a successful braze.

Brazing with copper (above 1650°F) or nickel-based metals (above 1850°F) requires that the joint tolerance is kept to an absolute minimum, and in some cases, assembled with an interference fit at ambient temperatures to ensure the correct joint tolerances while at the brazing temperature.

Induction Heating Theory

Induction heating systems provide a convenient and precise way to quickly and efficiently heat a selected area of an assembly. Induction heating is noncontact heating based upon transformer theory. The power supply is an AC source to the induction coil that becomes the primary windings of the transformer while the part to be heated is the transformer’s secondary — Fig. 2. The base materials of the workpiece heat because of their inherent electrical resistivity to the induced current flowing in the mass generated by the induction coil’s magnetic coupling.

Current passing through an electrical conductor (the workpiece) results in heating as current meets resistance to its flow. These losses are low in current flowing through aluminum, copper, and their alloys. These nonferrous materials require additional power to heat at similar rates to carbon steels that are more electrically resistive to current flow, which ultimately transforms into the heat necessary for the brazing process.

Heating is accomplished without physical contact between the heat source and the part. The alternating current tends to flow on the surface and there is a relationship between the frequency of the alternating current and the depth it penetrates the part. This is known as the reference depth of heating. Part diameter, material type, and wall thickness can have an effect on heating efficiency based on the reference depth.

The selection of the output power of the induction unit and the operating frequency of the system is dependent upon the workpiece. The power
range of this equipment is typically 5–50 kW with a medium operating frequency range of 3–50 kHz used on larger, heavier mass assemblies. High-frequency equipment is best utilized on thin cross-sectional assemblies for greatest efficiencies with a frequency range of 150–350 kHz.

The amount of power required (kW) is always dependent on the part symmetry and the material of the workpiece. Of great importance for induction brazing is having uniform heating of all parts to be soldered or brazed. Asymmetric parts, dissimilar masses, and nonuniform cross sections are often very difficult to achieve the appropriate uniformity in a single heat time. For this reason, timed ramp and soak functions or implementation of an optical pyrometer to control the power density are implemented in the heating event. This allows both induction and conduction to evenly distribute heat through the parts mass to achieve thermal uniformity at the faying surfaces.

**Induction Coil Design**

Fabricated from highly conductive copper tubing or plate, the induction coil’s design is influenced by the application, selection of frequency, power density, and heat time. The purpose of the inductor is to create a magnetic flux pattern to generate a current path in the workpiece to selectively heat the area of the assembly to be brazed.

The coil must be correctly positioned on the assembly allowing the required heating to be accomplished. The air gap or coupling space between the workpiece and the inside of the inductor should be minimized for reasons of efficiency. Typical design gaps of $\frac{1}{8}$ to $\frac{1}{4}$ in. are reasonable for brazing with a helical coil.

Irregularly shaped sections may need additional clearances thus require additional power to overcome these poor coupling efficiencies. These cases include situations where a round inductor with a large air gap or a nonencircling coil is needed to access the braze area — Fig. 3.

The area to be heated determines the length of the inductor. An inductor that is too short will require a longer heating time to allow the heat, by conduction, to cover the area. An inductor that is too wide will heat more metal than necessary, and therefore be less efficient. Many special designs of inductors for localized heating have been developed that heat efficiently without surrounding the workpiece.

**Induction Fixtures and Production Automation**

If the shape of the workpiece will not support itself in an upright or conventional position (self seating/self centering), a simple nesting fixture may be required. Materials for fixturing include nonmagnetic stainless steel, ceramics, heat-resistant composites, refractories, and high-temperature composites. Thermal expansion, material compatibility, and thermal conduction of the part during the brazing process are also considered when designing the holding fixture for repeatable everyday operation.

Stand-alone, inline, rotary, indexing, or continuous, a properly designed material handling system is critical to the success of a brazing process. It needs to retain its integrity throughout the rigors of daily part processing. The material handling system can be as simple as a stand-alone manually loaded system where an operator loads the parts into a holding fixture, or as complex as a fully automated system.
Controlled-Atmosphere Induction Brazing

Controlled-atmosphere induction brazing in an oxygen-free environment produces exceptional joint quality in a fluxless environment without scaling or oxidation — Fig. 4. The induction coil, in most cases, is within the closed inert atmosphere environment for selective heating of the braze area. In some others, the inductor may surround a nonconducting containment, such as a quartz tube.

These production systems can be as simple as a bell jar where the parts are positioned for process, heated, and cooled under the protective containment. Automated multistation systems (Fig. 5) allow continuous loading of assemblies into fixturing having a positive flow of inert gas designed to index through the heating and cooling needs of the braze assembly. After the heating is completed at the first station, the remaining stations are provided for cool down. To increase production, multiple parts can be brazed in a single heat.

Advantages of shielding with inert gases in a controlled-atmosphere induction brazing system are listed below.

- Little or no clean up of the finished brazed assembly,
- Removal of the fluxing preparation, application, and clean up steps in process,
- The gas shroud and tooling serve as workpiece holders in the process,
- Efficient energy usage by heating “on demand” in only the area that requires brazing,
- Near single-piece flow with reduced inventory over conventional batch processing,
- Reduced distortion by heating only the area needed to be brazed.

Shield gas selections include all noble gases depending upon the parts to be processed, but the most common are nitrogen, argon, and hydrogen. Carbon steel parts use argon or pure nitrogen with the Grade 5.0 (high purity). For high-alloy stainless steel parts, the cover gas is also pure nitrogen or a nitrogen-hydrogen gas mixture. The hydrogen content can be determined by the parts aesthetic finish requirements. Usually a 95% nitrogen and no greater than 5% hydrogen would be utilized in processing.

Conclusion

Controlled-atmosphere induction brazing using shielding gases is an innovative breakthrough in manufacturing technologies. The key advantages of induction brazing technology are noncontact heat transfer, excellent process repeatability, high efficiency, and rapid rate of heating. Long-term energy savings, high part quality, safety, and process control highlight the features of this technology, which is now gaining momentum, complementing or replacing conventional processes in the automotive, aerospace, environmental, and HVAC arenas.