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Joining components by induction heating, Part I

Professor Induction welcomes comments, questions, and suggestions for future columns. Since 1993, Dr. Valery Rudnev has been on the staff of Inductoheat Group, where he currently serves as group director – science and technology. In the past, he was an associate professor at several universities, where he taught graduate and postgraduate courses. His expertise is in materials science, heat treating, applied electromagnetics, computer modeling, and process development. He has 28 years of experience in induction heating. Credits include 16 patents and 128 scientific and engineering publications.

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Induction heating is commonly used to join components of an assembly by brazing, soldering, friction welding, bonding, or shrink fitting. The metals being joined can be either similar or dissimilar.[1]

In brazing, soldering, and friction welding, both of the components to be joined must be heated to approximately the same temperature. However, when bonding or shrink fitting, only one of the metal components might be heated.

This two-part column provides an overview of induction joining principles and presents several case studies. Part I, which follows, focuses on induction brazing and soldering, while Part II (*Heat Treating Progress*, May/June 2005) will cover induction bonding and shrink fitting.

Induction brazing/soldering

Brazing (Fig. 1) and soldering are popular induction joining applications. Joining is accomplished by melting a filler material (a brazing filler metal or solder). In all cases, the filler has a lower melting point than the liquidus temperatures of the materials being joined.

The joint area is heated to a temperature lower than the melting points of the workpieces, but higher than the melting point of the filler. When the filler material liquefies capillary action causes it to flow into the air gap of the joint, where it solidifies almost immediately, completing the joint.

During the brief time that the filler is a liquid it undergoes a diffusion-type chemical reaction with the surface of the base metal.[1] In soldering, this reaction takes place within a depth of a few micrometers, while in brazing (a higher temperature joining process) the depth of reaction is much greater.

Soldering is typically distinguished from brazing by the temperature at which the filler melts. The industry accepted definition: If the melting temperature of the filler is less than 450°C (840°F), then the process is soldering.[2,3]

Induction brazing and soldering have several advantages compared with heating the workpieces with a flame. Since the joint is heated in a localized area in a short time, the rest of the workpiece will not be significantly affected by temperature. This can be critical for controlling distortion, surface corrosion, and oxidation of the components. Other benefits include noticeably reduced grain growth, toxic fume emissions, and radiant heat.

Induction brazing and soldering usually are accomplished without the use of a protective atmosphere. However, if one is required, the induction coil can be placed in a gas-tight chamber containing argon, a H_2-N_2 mixture, or another gas. Induction joining also can be done in a vacuum chamber.

A final, major advantage of induction brazing/soldering is its ability to be automated. Once the process has been developed, there may be no need for operator intervention. The energy input is well-controlled, and results are reliable and consistent.

Process parameters

As with any induction application the success of an induction brazing/soldering operation is greatly affected by coil design, frequency choice, and the ability to have enough power to accomplish the job. A separate coil dedicated to the part being fabricated usually is required. However, depending upon part geometry, families of parts can sometimes be joined using the same coil.

Joining of dissimilar metals using the same power supply may result in noticeably different depths of heating

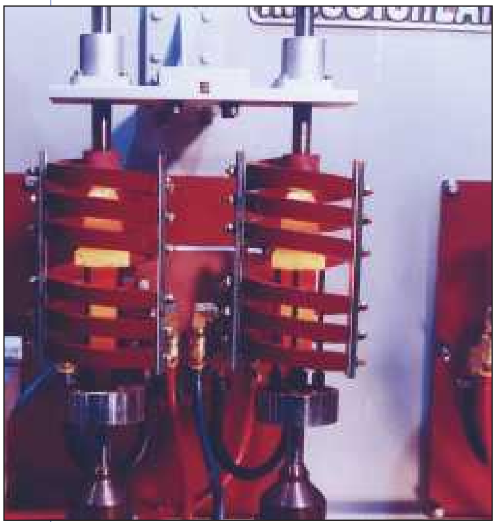

Fig. 1 — Induction machine for brazing tips to tool bits for use in the mining industry. With multiturn coils such as these, the electromagnetic field distribution can be tailored by varying the coupling gap and/or the distance between coil turns. Photo courtesy Inductoheat Inc.

and heat intensities for the components being joined. This is because the electrical resistivity and magnetic permeability of the material directly affect the penetration depth at a given frequency.[1] The metals' electromagnetic properties also affect their ability to attract a magnetic field. As a result, each electrically conductive component might be heated differently while using the same frequency and applied power. Note, too, that differences in thermal conductivity will lead to different rates of heat transfer (heat soaking). This results in different masses of metal being heated.

The induction coil usually can be arranged to provide uniform heating: the electromagnetic field and induced eddy currents are redirected to compensate for differences in the ability of components to be heated.[1]

It is also important to evaluate differences in the materials' thermal expansion coefficients. Thermal expansion should be considered when designing holding fixtures and choosing joint gaps. (A gap that is too large or too small will prevent optimal filler material flow.)

High frequency is often chosen for brazing applications. The main reason: In many cases, thin-wall or small parts are being joined. In addition, a high frequency also makes it easier to localize the heat.

Coil design features

A wide variety of shapes and sizes of inductors is available for induction brazing/soldering. If frequent coil changes are required to accommodate a range of components, quick coil-change adapters can be used to speed up the inductor replacement process.

Multiturn or single-turn encircling coils are used when one joint at a time is to be made. Pancake, channel, and hairpin coils are also commonly used when assemblies are presented to the induction coil on a continuous basis, such as via a conveyor or rotary table.

In addition to inductor design, the method by which the individual components are fixtured (or held together) during the joining operation has a tremendous effect on joint quality.

Brazing/soldering inductors are commonly made from water-cooled copper tubing configured to conform around the joint area. Tubing size and shape depend on the geometry of the brazed component, and the frequency and coil current.[1]

In a well-designed induction brazing/soldering system, the joint area and the filler material need to reach the brazing/soldering temperature at the same time. Therefore, part of the "secret to success" is to choose the combination of frequency, power density, and coil geometry that provides uniform heating regardless of the materials of construction and geometries of the components being joined. An ability to conduct a numerical computation is a prerequisite for obtaining these optimal process design parameters.

The highest coil electrical efficiencies are obtained when there is a good coupling (small gap) between the induction coil and the heated workpiece. However, in induction brazing/soldering, a small "coil-to-workpiece" gap might not be optimum. For example, it may be more desirable to have a wider gap to promote slightly slower but more uniform heating. The three induction brazing case studies that follow highlight the importance of the coupling gap.[1]

Example: Dissimilar materials

To achieve uniform heating when brazing dissimilar materials, the inductor design should provide compensation for differences in the heating characteristics of each component. This is especially true when joining a nonmagnetic to a magnetic material.

Figure 2 is a sketch of an induction system for joining carbon steel (magnetic) to copper (nonmagnetic). The "improper design" (a) is a multiturn inductor with a uniformly spaced gap. The steel will better attract the magnetic field, and experience a much greater heat intensity than the copper.

Worsening this scenario is the fact that copper has a much lower electrical resistivity than carbon steel. This further reduces the nonmagnetic material's ability to be heated by induction. In addition, copper is not only a good electrical conductor, but is also a good thermal conductor, having a thermal conductivity much higher than that of steel. Therefore, copper absorbs heat much quicker than steel, resulting in heating of a larger mass of the copper component of the joint.

As a result, the "improper" coil design will overheat the carbon steel and underheat the copper. More heat must be generated within the copper to obtain a heating condition similar to that of the steel.

The alternative, "proper" coil design (b) features several coil turns decoupled from the carbon steel component. The larger air gap provides a reduced magnetic field intensity in this region. A reasonably uniform heating pattern for both materials results.

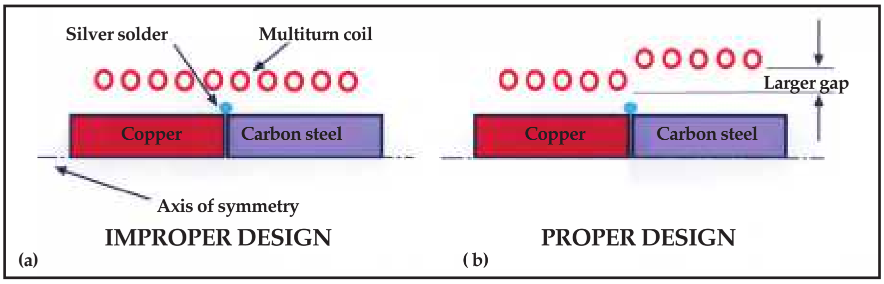

Fig. 2 — Brazing dissimilar materials requires a nonstandard coil configuration. (a) A uniform coupling gap overheats the carbon steel and underheats the copper in this example. (b) A larger coupling gap on the steel portion of the joint provides a more uniform heating pattern for both materials. (Ref. 1)

Example: Different cross sections

Care must be taken when brazing materials that have different cross sections (Fig. 3). In this example, tubes made of the same metal but having different wall thicknesses are being joined. Similar to the previous case study, if a multiturn coil with a uniform coupling gap is chosen (a), the thin-wall tube will overheat. By intentionally weakening the coil coupling in the area of the thin-wall tube

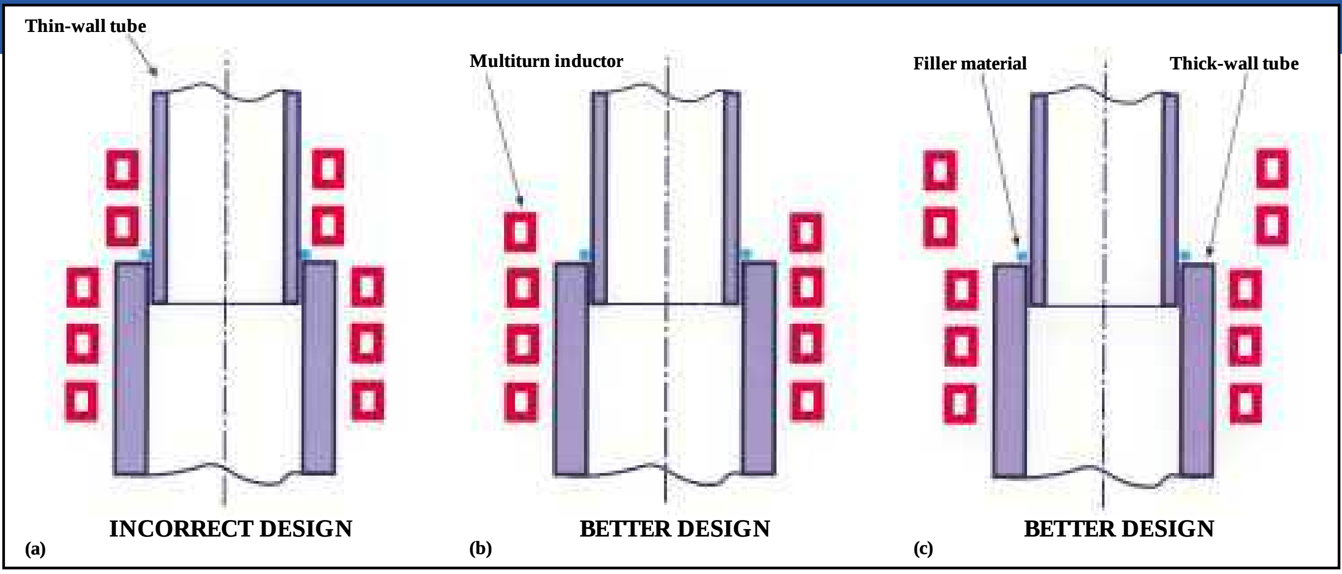

Fig. 3 — This example involves joining similar materials having different cross sections. (a) A uniform coupling gap results in overheating of the thin-wall tube. (b and c) Better designs concentrate heat into the more massive thick-wall tube, producing reasonably uniform heating.

(b and c), the electromagnetic field will be redistributed and more uniform heating will result.[1]

Example: Mass, shape, thickness

The braze joint sketched in Fig. 4 has components that differ not only in thickness but also in shape and mass. In this case, it is necessary to heat both the joint area and the adjacent mass of the workpiece to ensure a good braze. The "incorrect" coil placement (a) has uniform spacing between the inductor and the components to be joined. The thin-wall tube component will be heated more intensely compared with the larger mass of the flanged component. This is due to the tube's lower mass and to an electromagnetic "ring" effect appearing in the coil.[1] In the "correct" coil configuration (b), heat is intentionally redirected toward the flange by weakening the ring effect and taking advantage of the electromagnetic proximity effect.

When a multiturn coil is used, the redistribution of the electromagnetic field can be achieved not only by varying air gaps between certain turns and the components to be brazed but also by adjusting the spacing between turns. This enables the power density to be tailored to specific areas of the assembly. Smaller distance between turns results in increased power density and vice versa (Fig. 1).

Complex brazed assemblies might have features that are located close to the joint area and that could be damaged if overheated. In these cases, magnetic flux concentrators and / or magnetic shields can be added to the coil. In other cases, water-cooled chiller blocks can be used at areas of concern (if sufficient space is available). Use of chiller blocks may require a power increase to provide the needed heating condition for brazing.[1]

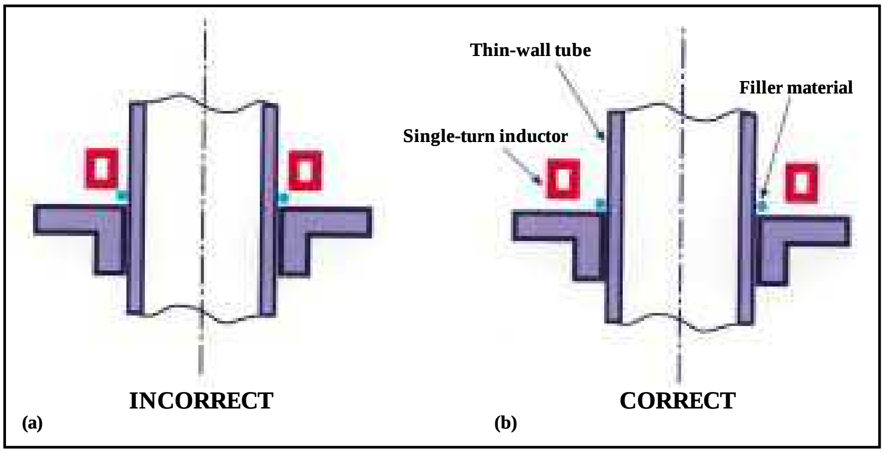

Fig. 4 — Coupling gaps also can be changed to accommodate differences in component shape and mass, as well as thickness. (a) Overheating of a thin-wall area, due to a relatively small mass and incorrect placement of the inductor. (b) Repositioning the induction coil ensures uniform heating of the entire joint area.

Filler metals and fluxes

Hundreds of filler materials (filler metals and solders) have been developed for a myriad of metal joining applications. Selection factors include the physical and mechanical properties, melting characteristics, and product form required.[2–4] Properties of interest include melting point, flow point, fluidity, and "wetting" characteristics. (Wetting characteristics indicate how well the liquid filler will flow into the joint due to capillary action.)

Fillers are designed to accommodate special application requirements. For example, electrical resistivity and thermal conductivity may be considerations when brazing or soldering electronic devices. In other cases, corrosion resistance may be important. In still others, there may be requirements for a chemical composition that will eliminate toxic fumes, be nonvolatile, reduce dross, and / or provide ductile, fatigue-resistant joints. The availability of lead-free fillers can be critical in food and potable water applications. Appearance or cost also can be major drivers.

Brazing filler metals and solders are categorized as to their principle alloying element. Lists of common filler metals / solders and their approximate brazing / soldering temperature ranges can be found in Ref. 1–4. *Continued*

Filler material is typically available as wire, rod, strip, powder, and preforms. Among the preforms are shims, washers, rings, shaped wire, slugs, and stamped shapes.[4]

Fluxes also play an important role in brazing / soldering operations. The flux helps protect both the filler and base metal from oxidation during heating.[2–4] Fluxing action at the joint area dissolves and absorbs any oxides that form. This is essential to proper wetting of the components to be joined by the filler metal / solder. Flux is applied to clean and degreased surfaces just prior to brazing / soldering.

Fluxes are designed for specific applications and combinations of temperature range and filler material. Common forms are paste, powder, and liquid.

Fixturing and handling

Proper fixturing and handling of the parts to be joined is as critical as uniformity of heating and filler material / flux selection. The best scenario for brazing from a fixture prospective is when the components are self-aligning and their shapes and weights are such that the assembly holds itself together during the entire process. In many cases, however, clamps or other fixtures are needed to maintain component alignment. Fixtures are made of nonmagnetic metals, heat-resistant plastics and composites, and ceramics.

There are several basic ways to semiautomate induction brazing / soldering equipment. The most common are manually loading a magazine, conveyor, or rotary table. The operator assembles the components and either manually feeds filler material or positions preforms. The operator also might use clamps or other holding devices.

When high production is required, an automated setup is preferred. These systems assemble the components, feed filler material or place preforms, and hold the assembly until the joint has solidified. Induction heating can be done at a single station or at multiple stations if the assembly has more than one joint. Certain part geometries enable a continuous-feed of assemblies. These automated systems employ through-feed or channel-type inductors.

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