HARRIS

A LINCOLN ELECTRIC COMPANY

LINCOLN ELECTRIC

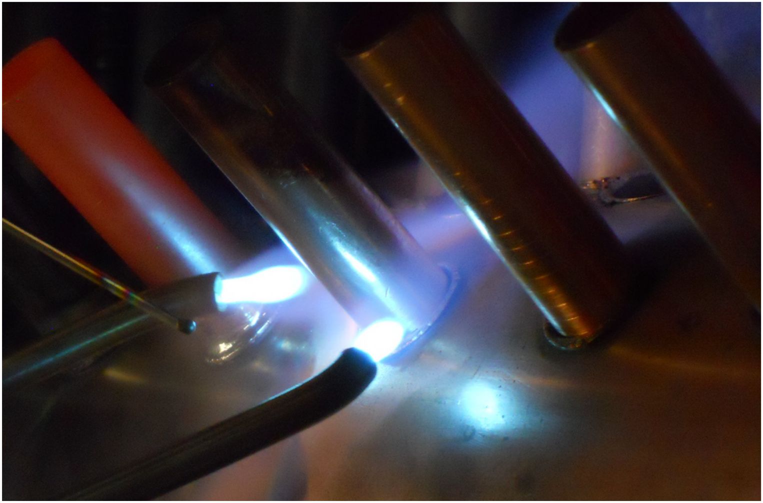
THE PATH TO BRAZE QUALITY

A COMPREHENSIVE EVALUATION OF THE BRAZING PROCESS IS NECESSARY TO IMPROVE PRODUCTION RESULTS

BY **ROBERT HENSON**

A pragmatic approach to braze quality considers three interrelated concepts: establishing and documenting a brazing procedure, understanding and applying correct brazing principles, and post-braze inspection guidelines. This article reviews those factors.

POST-BRAZE INSPECTION



Brazing is primarily defined by the ability of the molten filler metal to spread and adhere to the base metal (wetting), and its ability to flow into the tight spaces between parts (capillary action).

Let's look at the last concept first. Braze inspection is necessary. You need to look for obvious surface imperfections, and additional nondestructive measurements, such as leak or pressure tests, are often a valuable quality check. It is important to define inspection requirements that meet your benchmarks and, equally important, your customer's needs.

A valuable resource is the American Welding Society (AWS) document C3.4/C3.4M, *Specification for Torch Brazing*. AWS also has related C3 documents that cover other processes such as induction, furnace, resistance, and aluminum brazing. The C3.4 specification is designed to "standardize process requirements and brazed joint quality requirements for all applications requiring brazed joints of assured quality." The document classifies brazed joints based on design requirements and consequences of their failures. It provides a framework for inspection and evaluation of braze discontinuities. A companion document, ISO 18279, *Brazing — Imperfections in brazed joints*, outlines quality levels and details braze imperfections. It provides comprehensive illustrations regarding discontinuity types and limits.

While not diminishing the significance of post-braze inspection, there is an inherent problem. You cannot view inside of the brazed connection. Inspection is typically an external visual check, and from that vantage point the braze may look satisfactory, as seen in **Fig. 1.**

Fig. 1 Exterior view of a copper-brazed tube

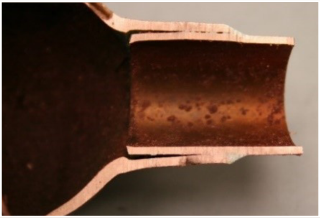


Fig. 2 Sectioned brazed joint showing lack of filler metal penetration

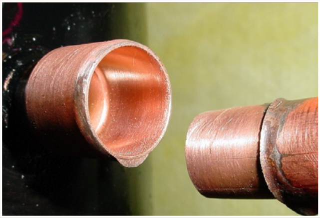


Fig. 3 In-service failure

Fig. 4 Peel test results

AS FIGURES 2, 3, AND 4 ILLUSTRATE, looks can be deceiving. Visually, these brazed joints appeared acceptable, but if there is limited braze penetration, it can lead to eventual service failure.

Unless we include ultrasonic or radiographic tests to evaluate internal integrity, we need to establish a confidence level for assurance that the entire braze is sound. This requires an upstream approach to control the braze operation before it gets to the inspection phase.

BRAZING PROCEDURE

A documented brazing procedure is the first step. It is the foundation for braze quality and establishing process discipline. Most companies have defined work instructions, but braze joint detail may be lacking. Brazing requires that multiple variables be controlled: base metal, filler metal, clearance, cleanliness, flux, and heating all play significant roles. A sound braze is the sum of its parts.

A brazing procedure outlines part design and brazing conditions. The procedure should be validated by testing to confirm that parts produced following procedure guidance will meet requirements. Once established, you need to confirm that brazer or brazing operator skill levels will produce these results.

One effective approach is to use AWS B2.2, *Specification for Brazing Procedure and Performance Qualification*. This document can serve as a helpful template to establish a program to control the process and evaluate operator brazing skill.

BRAZING PRINCIPLES

Brazing is primarily defined by the ability of the molten filler metal to spread and adhere to the base metal (wetting), and its ability to flow into the tight spaces between parts (capillary action). Understanding these fundamentals is crucial to evaluating your braze operation.

WETTING

Several factors influence a brazing filler metal's ability to wet a base metal, including surface cleanliness, presence of oxide layers, temperature, and brazing time. In a brazed (or soldered) joint, there are cohesive forces within the liquid filler metal and adhesive forces between the liquid filler metal and the solid base metal. When adhesive forces are larger than cohesive forces, the filler metal will adhere to (wet) the base metal — **Figures 5 and 6.** Metal surface cleanliness is important because surface oxide, grease, dirt, and other contaminants prevent good contact between the filler metal and the base metal. Proper pre-braze cleaning is necessary as is some type of flux, or protective atmosphere, to dissolve surface oxides and inhibit further oxide formation during heating. These wetting aspects must be considered because they influence what occurs within the capillary space during brazing.

Fig. 5 Solder nonwetting without flux

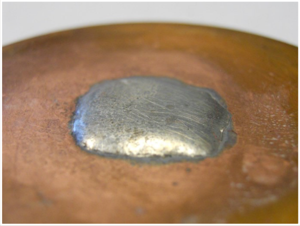


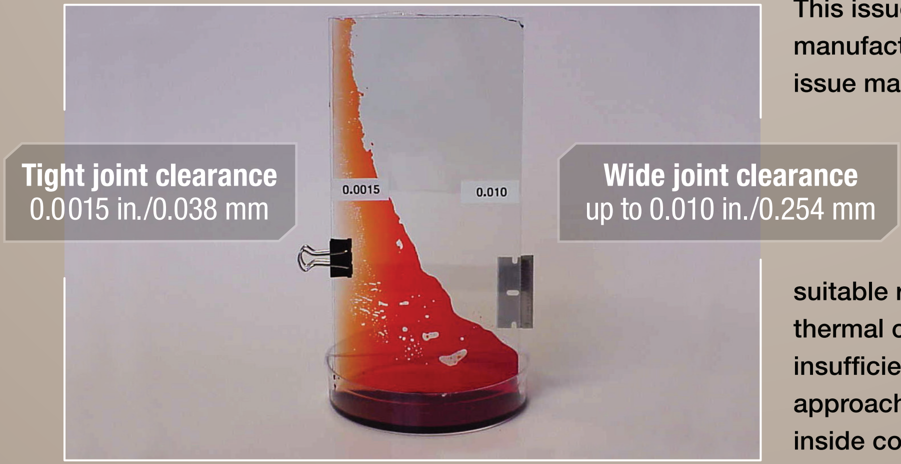
Fig. 6 Solder wetting when flux is applied

CAPILLARY ACTION AND CLEARANCE

Most production, torch-brazed connections are lap, or socket, joints. This design requires drawing the molten filler metal into the space between the two members — **Figure 7.** Capillary action is the driving force for this brazing alloy penetration. It is the key to strength and integrity for these connections.

Maintaining proper clearance between parts is important to facilitate capillary flow. The ideal clearance depends on base metal, filler metal, and process, but for most torch brazing applications a 0.002–0.005 in. (0.025–1.27 mm) joint clearance is suggested.

A simple test illustrates how clearance affects capillarity. **Figure 8** shows how a liquid flows between varying space between two plates. It can be noted how capillary flow diminishes as the clearance increases.



Tight joint clearance
0.0015 in./0.038 mm

Wide joint clearance
up to 0.010 in./0.254 mm

Fig. 8 Capillary flow experiment

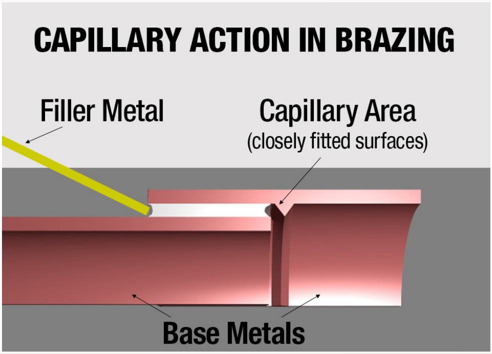


Fig. 7 A brazed joint illustration

Inconsistent clearance is an all too common problem in production assemblies and it reduces brazing filler metal flow. **See Figures 9–11.**

The converse problem is insufficient clearance. Notice in Figure 8 the area around the left side clamp. It is devoid of colored fluid because, at that point, the clamp imposes a press fit. Brazing filler metal cannot flow into areas with insufficient capillary space.

This issue results from inability to maintain manufacturing tolerance. It can also be a design issue manifested when brazing dissimilar metals.

Consider a copper-to-steel assembly when heated copper expands at a greater rate than steel. A joint with copper inside the steel may have suitable room temperature clearance, but different thermal coefficients of expansion may result in an insufficient joint clearance when heated. A preferred approach to this combination is for steel to be inside copper. The joint can be designed to provide proper braze temperature clearance and puts the braze in compression during cooling.

Fig. 9 Excessive joint clearance

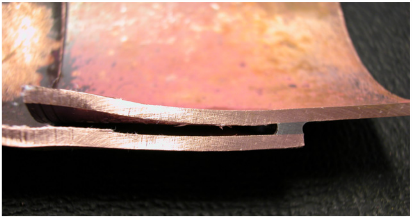


Fig. 10 Insufficient penetration

Fig. 11 Incomplete fill

HEATING

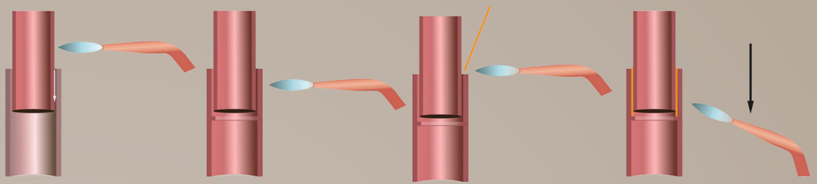


Fig. 12 Tube-heating sequence

Part heating and filler metal application are other functions that greatly influence braze quality. Molten brazing filler metal will flow toward the heat. To facilitate penetration into the joint, your heating goal should be to simultaneously bring both parts to brazing temperature. This is complicated by part design, but here are some general approaches.

Where parts are both the same metal with thickness, heat input should be about the same for each side. For a tube into a fitting, the heating pattern and filler metal approach is illustrated in **Figure 12.** Heat the tube, male part first, to draw heat inside, then heat the coupling female to evenly bring both parts to temperature and draw the braze material into the capillary.

As part thickness changes, the heating sequence and duration should be altered. For the same metal but differing thickness, the thicker part will typically require more heat. For dissimilar metals, another factor becomes relevant. Metals conduct heat at different rates. Thermal conductivity for common metals is illustrated in **Figure 13.** This phenomenon indicates, for copper-to-steel connections, copper may require additional heat to compensate for its higher conductivity. Copper will conduct heat away from the joint, but the less conductive steel side will heat more rapidly.

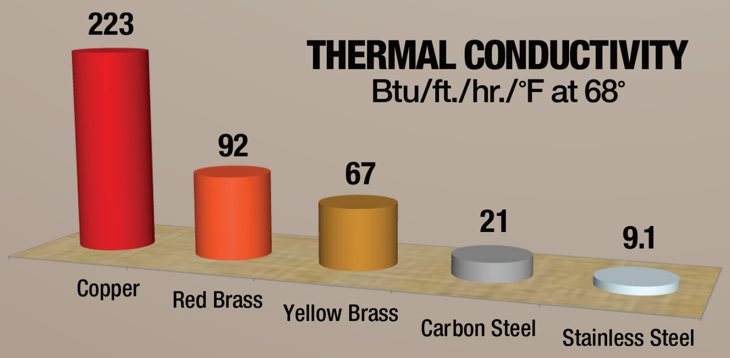


Fig. 13 Thermal conductivity of common metals

There is another heating consideration. Elements melt at a single temperature. Brazing filler metals, however, are multi-element so they exhibit a different melting characteristic.

They begin melting at one temperature (solidus) and melt completely at a second, higher temperature (liquidus). Between the solidus and liquidus, they are a combination of solid and liquid, and this temperature differential is called the melting range. Some brazing filler metals have a short melting range. A few, called eutectics, melt at a single temperature. Others have wide melting ranges. Most recommend brazing temperature ranges start at, or slightly above, the liquidus. There are exceptions, as brazing temperature is related to the amount of solid and liquid present at a given temperature. For production brazing applications, however, you generally want to raise the part temperature rapidly to this recommended temperature so the filler metal quickly melts when applied to the joint. For filler metals with narrow melting ranges, this usually is not a problem. For those with wide melting ranges, it can be problematic. If these alloys are slowly heated or applied prematurely, you can experience liquation, the separation of the lower and higher melting alloy constituents. The lower melting composition will flow into the joint, leaving a higher melting temperature rough deposit (“skull”) remaining. Liquation should be avoided to ensure braze joint integrity and improve surface appearance.

FURTHER STUDY

This outline presents some thoughts about braze quality improvement. It highlights key areas that, if addressed, have shown to improve production braze results. There are several publications that provide detail on these and many other important braze aspects. Highly recommended is the AWS *Brazing Handbook*, an invaluable reference to augment your brazing knowledge. In addition, other AWS Standards can guide manufacturing engineers in understanding and evaluating brazed joints. **Visit pubs.aws.org**

***Robert Henson** is Technical Director, Harris Products Group div. of The Lincoln Electric Co., Mason, Ohio.*

ABOUT THE HARRIS PRODUCTS GROUP

The Harris Products Group, a Lincoln Electric company with headquarters in the U.S., is a world leader in the design, development, and manufacture of cutting, welding, brazing, and soldering equipment, consumables and gas distribution systems. Products are sold and used in more than 90 countries.

For more information about The Harris Products Group and its products and services, please visit us at

WWW.HARRISPRODUCTSGROUP.COM

LINCOLN® ELECTRIC

HARRIS
A LINCOLN ELECTRIC COMPANY