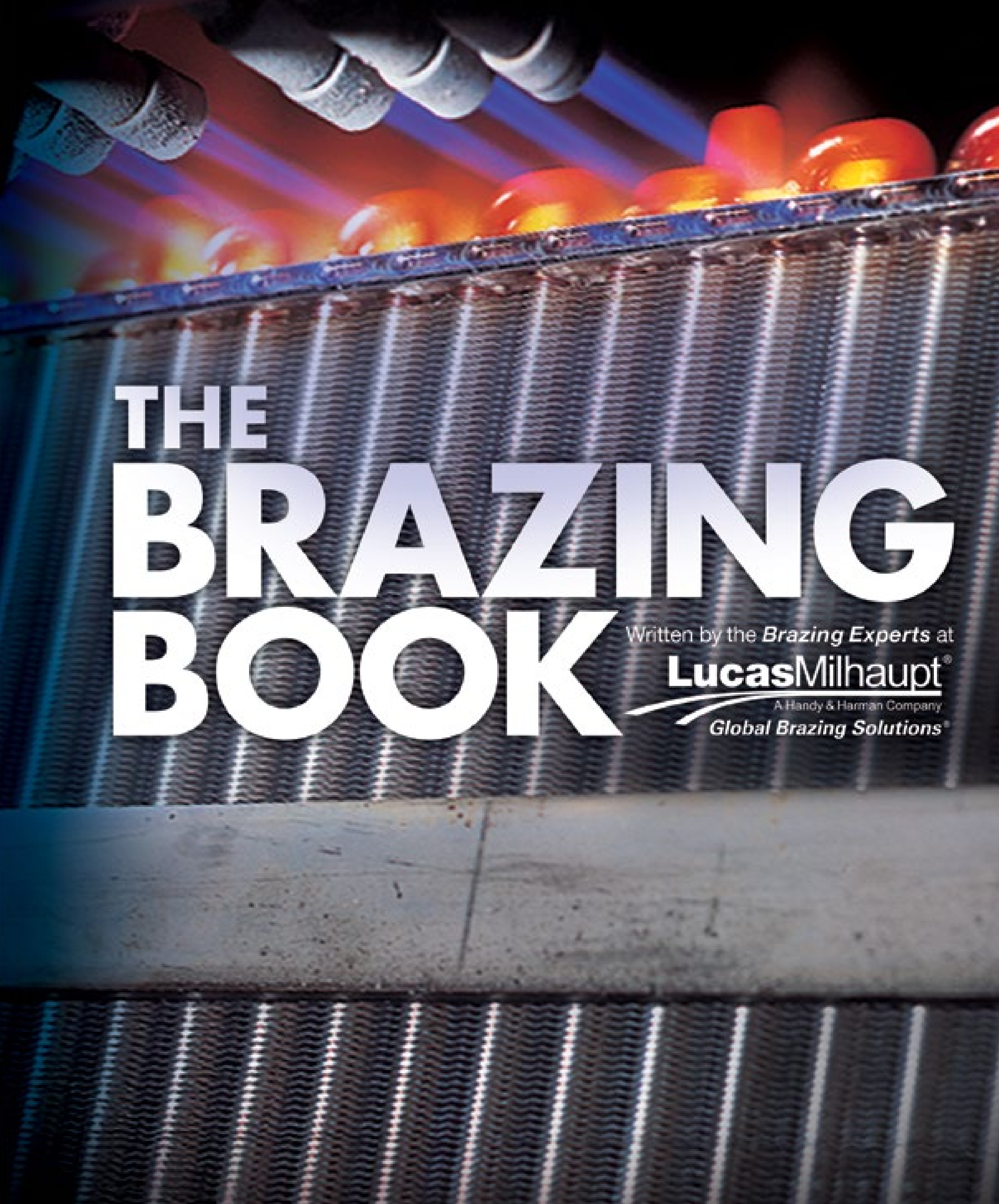


THE BRAZING BOOK

Written by the *Brazing Experts* at

LucasMilhaupt®

A Handy & Harman Company

Global Brazing Solutions®

Contents

Section 1:The Idea of Brazing

Section 2:Brazing in Action

Section 3: Handy &Harman Brazing Materials

Reference Charts, Tables and Procedures

Secton 4: The Lucas-Milhaupt/Handy & Harman Advantage

Secton 5: Available Reference Materials

LucasMilhaupt
A Handy & Harman Company

The Brazing Book

This book contains a significant amount of information on the process of brazing. It was originally created by Handy & Harman to assist both the novice brazer and the seasoned engineer. For years, this publication has been well received and a very useful tool.

Lucas-Milhaupt, Inc., a Handy & Harman Company, has updated this publication to incorporate the many changes that have occurred within the industry. However, the purpose of this book remains the same: to expand the applications of brazing by relaying the many advantages of it as a metal-joining method—while being quite candid about its limitations.

And we highlight the many people and industries who are now using brazing wherever possible to increase their manufacturing efficiencies.

For ease of understanding, we've divided the book into five main sections.

Section One, "The Idea of Brazing," explains exactly what brazing is, where to use it, and how to perform it properly.

Section Two, "Brazing in Action," presents detailed photographic case histories illustrating some of the many applications in which brazing is used today.

Section Three, "Choices In Brazing Materials," lists and describes the many brazing products available from Handy & Harman and Lucas-Milhaupt and features useful selection charts to help you choose the best filler metals and fluxes for your particular brazing application. For your convenience, we've also included a number of technical reference tables and related information.

Section Four, "Technical Support Services," describes some of the technical services and types of equipment available through Handy & Harman/ Lucas-Milhaupt and their sales and service locations throughout the world.

Section Five, "Available Reference Materials," lists a variety of other brazing related information available to further assist you in your brazing operations.

We know you'll find The Brazing Book informative and helpful. We hope you'll find it interesting as well.

The Handy & Harman/Lucas-Milhaupt Story

HANDY & HARMAN HISTORY

Handy & Harman is a widely diversified manufacturing company with a rich history of product and process innovation, and an exciting future. Formed in 1867, Handy & Harman is best known in the precious metals market, but also fabricates thousands of products for a broad spectrum of industrial users.

As early as 1905, Handy & Harman introduced its first line of brazing alloys and fluxes. These "solders" became invaluable in joining all types of metals into strong, leak-tight bonds. In response to growing demand from industrial markets, Handy & Harman's research engineers developed standardized filler metals in strip, rod, and wire form, to meet a wide range of metal-joining applications. These new alloys were the original Easy-Flo® and Sil-Fos® products. During World War II, this new technology proved invaluable in the mass production of aircraft, ships, tanks, guns and ammunition.

THE LUCAS-MILHAUPT CONNECTION

Lucas-Milhaupt was founded in 1942 as a tool manufacturer, but soon turned to the production of silver alloy brazing preforms for the joining of metals. The use of preforms was a new technology that accelerated greatly due to the demands of World War II. From 1944 to 1967 the company grew steadily, adding copper, brass and aluminum brazing preforms and soft solder forms to the product line. The arrival of the electronic age brought with it a demand for all types of brazing and soldering methods and products. Lucas-Milhaupt grew steadily developing advanced technology along the way.

In 1967, Lucas-Milhaupt was acquired by Handy & Harman. Becoming part of a large, diversified firm supplied Lucas-Milhaupt with additional management skills and financial resources, allowing the company to grow even further. In turn, Lucas-Milhaupt provided Handy & Harman with new brazing products and fabrication services to add to its already vast offerings.

Over the years, Handy & Harman technicians continued to develop several groundbreaking new product families including: BRAZE™ (now known as SILVALOY®), cadmium free filler metals for specialized applications; PREMABRAZE®, high-purity vacuum tube grade alloys for electrical/electronic applications; HANDY® FLUX, specialized fluxes for various high and low temperature applications; and TRIMET®, a tri-metal clad strip for joining mining and cutting tools.

Meanwhile, Lucas-Milhaupt continued to expand their capabilities in metal-joining technology. Their inventory of alloys and forms has grown to be the most extensive in the industry. They also feature over 4,000 stockdies for stamping and a complete tool room, enabling them to custom manufacture brazing forms specifically to meet a customer's unique application. In addition, their Technical Support group provides a variety of brazing services to assist customers in their metal-joining operations.

A look at Handy & Harman of Canada, Limited.

In 1936, Handy & Harman of Canada, Limited, began business in Toronto, Ontario, as a supplier of sterling silver to the silversmith. At this same time, with our newly developed Easy-Flo® and Sil-Fos® silver brazing alloys, we initiated the modern era of low temperature production brazing across Canada.

Over the following years, the company has continued as a precious metal fabrication leader and innovator, supplying sophisticated and specialized products to the metal user. Our refining operation utilizes the latest equipment and refining techniques to ensure efficient, quick returns for our customers.

Today, with a modern and environmentally conscious facility in Rexdale, Ontario, and supported by other Handy & Harman plants in the United States, Europe, and the Far East, we continue to expand and diversify, offering a broad range of products and services to Canadian industries involved in metal joining and the arts.

Section 1: The Idea of Brazing

What brazing is all about.

What is brazing?

Brazing is the joining of metals through the use of heat and a filler metal—one whose melting temperature is above 840°F (450°C) but below the melting point of the metals being joined.

(A more exact name for the brazing process discussed in this book may be "silver brazing," since in most cases the filler metal used is a silver alloy. To remain brief, we'll use the term "brazing" throughout this book, with the understanding that we are referring to a torch brazing process with a silver-bearing filler metal. Where exceptions occur, it will be noted.)

Brazing is probably the most versatile method of metal joining today, for a number of reasons.

Brazed joints are strong. On nonferrous metals and steels, the tensile strength of a properly made joint will often exceed that of the metals joined. On stainless steels, it is possible to develop a joint whose tensile strength is 130,000 pounds per square inch. (896.3 megapascal [MPa]).

Brazed joints are ductile, able to withstand considerable shock and vibration.

Brazed joints are usually easy and rapidly made, with operator skill readily acquired.

Brazing is ideally suited to the joining of dissimilar metals. You can easily join assemblies that combine ferrous with nonferrous metals, and metals with widely varying melting points.

Brazing is essentially a one-operation process. There is seldom any need for grinding, filing or mechanical finishing after the joint is completed.

Brazing is performed at relatively low temperatures, reducing the possibility of warping, overheating or melting the metals being joined.

Brazing is economical. The cost-per-joint compares quite favorably with joints made by other metal joining methods.

Brazing is highly adaptable to automated methods. The flexibility of the brazing process enables you to match your production techniques very closely to your production requirements.

With all its advantages, brazing is still only one of the ways in which you can join metals. To use brazing properly, you must understand its relationship to other metal jointing methods.

What are some of those methods and which should you use where?

The versatility of brazing.

- *Strong joints*
- *Ductile joints*
- *Ease of operation*
- *Suited to dissimilar metals*
- *One-operation process*
- *Requires low temperatures*
- *Economical*
- *Highly adaptable to automation*

The many ways to join metals.

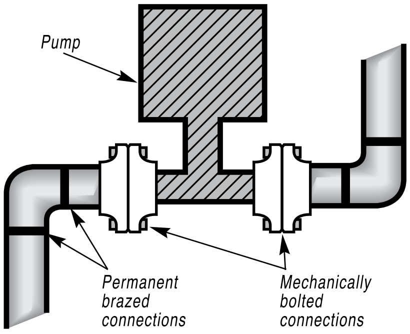
Brazing, as we've noted, relies on heat and a filler metal to join metals.

There is nothing unique about this. Welding and soldering are similar in these respects. And metals can also be joined efficiently and economically without the need for heat or a filler metal at all, by mechanical fastening or adhesive bonding.

When would you use brazing, rather than one of these other methods? It depends on the circumstances.

Let's start our evaluation of brazing as a metal joining method by eliminating those situations were brazing is generally *unsuitable*.

The first of these situations is the *non-permanent* joint. This is the joint that's made with future disassembly in mind. (For example—a pump connected to a piping assembly.)



The pipes won't wear out—but some day the pump will. It's easier to disassemble a threaded or bolted pump connection than a brazed connection. (You can "de-braze" a brazed joint if you have to, but why plan on it?) For the typical non-permanent joint, mechanical fastening is usually the most practical method.

There's another kind of joint where brazing will likely be your last, rather than your first, consideration. And that is the permanent, but *low-strength* joint. If you're joining metal assemblies that won't be subjected to much stress or strain, there are frequently more economical ways to join them than by brazing. (Mechanical fastening, for example, or soft soldering or adhesive bonding.) If you are selecting a method to seal the seams of tin cans, there is nothing to stop you from brazing. Yet soft-soldering would be perfectly adequate for this low-stress type of bond. And soft-soldering is generally less expensive than brazing.

In these two areas—the *non-permanent* joint and the permanent but low-strength joint—other joining methods are adequate for the job and usually more economical than brazing.

Where does brazing fit in?

Consider brazing when you want *permanent* and *strong* metal-to-metal joints.

Mechanically-fastened joints (threaded, staked, riveted, etc.) generally don't compare to brazed joints in strength, resistance to shock and vibration, or leak-tightness.

Adhesive bonding and soldering will give you permanent bonds, but generally neither can offer the strength of a brazed joint—strength equal to or greater than that of the base metals themselves. Nor can they, as a rule, produce joints that offer resistance to temperatures above 200°F (93°C).

If you want metal joints that are both permanent and strong, it's best to narrow down your consideration to *welding* and *brazing*.

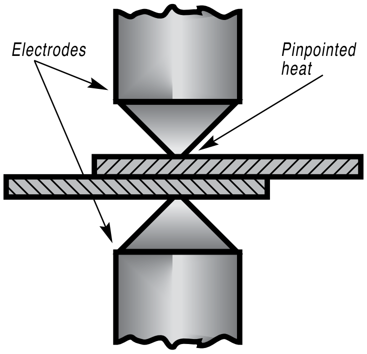
Welding and brazing both use heat. They both use filler metals. They can both be performed on a production basis. But the resemblance ends there. They work differently, and you need to understand the nature of that difference to know which method to use where.

How welding works.

Welding joins metals by melting and *fusing* them together, usually with the addition of a welding filler metal. The joints produced are strong, usually as strong as the metals joined or even stronger.

In order to fuse the metals, a concentrated heat is applied directly to the joint area. This heat is high temperature. It must be—in order to melt the "base" metals (the metals being joined) and the filler metals as well. *So welding temperatures start at the melting point of the base metals.*

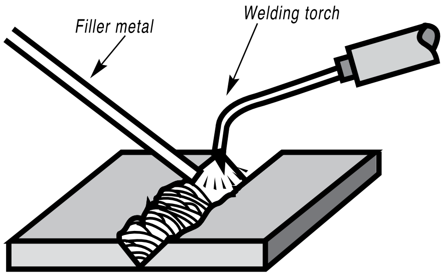
Because welding heat is intense, it is impractical to apply it uniformly over a broad area. Welding heat is typically localized, *pinpointed* heat. This has its advantages. For example, if you want to join two small strips of metal at a single point, an electrical resistance welding setup is very practical.



This is a fast, economical way to make strong, permanent joints by the hundreds and thousands.

However, if the joint is *linear*, rather than *pinpointed*, problems arise. The localized heat of welding tends to become a disadvantage. For example, suppose you want to butt-weld two pieces of metal—start by beveling the edges of the metal pieces to allow room for the welding filler metal. Then weld, first heating one end of the joint area to melting temperature, then slowly traveling the heat along the joint line, depositing filler metal in synchronization with the heat.

This is a typical conventional welding operation. Let's look at its characteristics.



It offers one big plus—strength. Properly made, the welded joint is at least as strong as the metals joined.

But there are minuses to consider.

The joint is made at high temperatures, high enough to melt both base metals and filler metal. High temperatures can cause problems, such as possible distortion and warping of the base metals or stresses around the weld area.

These dangers are minimal when the metals being joined are thick. But they may become problems when the base metals are thin sections.

High temperatures are expensive as well since heat is energy, and energy costs money. The more heat you need to make the joint, the more the joint will cost to produce.

Now consider the automated process. What happens when you join not *one* assembly, but hundreds or thousands of assemblies? Welding, by its nature, presents problems in automation. We know that a resistance weld joint made at a single point is relatively easy to automate. But once the point becomes a line—a *linear* joint—the line has to be *traced*. It's possible to automate this tracing operation, moving the joint line, for example, past a heating station and feeding filler wire automatically from big spools. But this is a complex and exacting setup, warranted only when you have large production runs of identical parts.

Of course, welding techniques continually improve. You can weld on a production basis by electron beam, capacitor discharge, friction and other methods. But these sophisticated processes usually call for specialized and expensive equipment and complex, time-consuming setups. They're seldom practical for shorter production runs, changes in assembly configuration or—in short—typical day-to-day metal joining requirements.

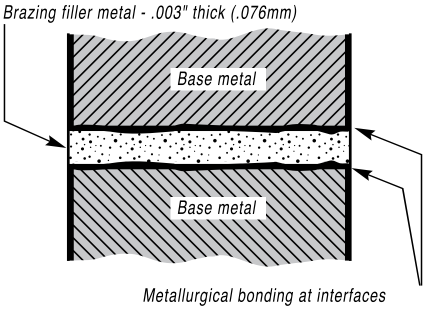
How brazing works.

A brazed joint is made in a completely different way from a welded joint.

The first big difference is in temperature. Brazing *doesn't melt* the base metals. *So brazing temperatures are invariably lower than the melting points of the base metals.* And, of course, always significantly lower than welding temperatures for the same base metals.

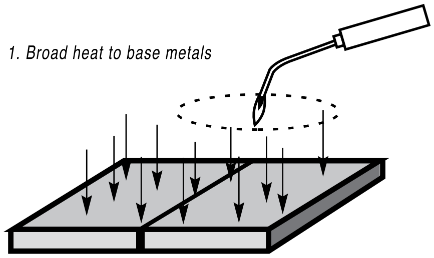
If brazing doesn't fuse the base metals, how does it join them?

It joins them by creating a metallurgical bond between the filler metal and the surfaces of the two metals being joined.

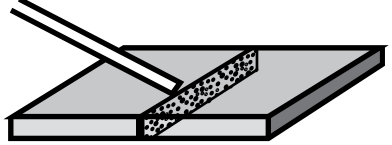


The principle by which the filler metal is drawn through the joint to create this bond is *capillary action*. In a brazing operation, you apply heat broadly to the base metals. The filler metal is then brought into contact with the heated parts. It is melted instantly by the heat in the base metals and drawn by capillary action completely through the joint.

1. Broad heat to base metals



2. Filler metal applied, instantly melted and drawn through joint



This, in essence, is how a brazed joint is made.

What are the advantages of a joint made this way?

Advantages of a brazed joint.

First, a brazed joint is a strong joint. A properly-made brazed joint (like a welded joint) will in many cases be as strong or stronger than the metals being joined.

Second, the joint is made at relatively low temperatures. Brazing temperatures generally range from about 1150°F to 1600°F (620°C to 870°C). Most significant, *the base metals are never melted*.

Since the base metals are not melted, they can typically retain most of their physical properties. And this "integrity" of the base metals is characteristic of all brazed joints, of thin-section as well as thick-section joints. Also, the lower heat minimizes any danger of metal distortion or warping.

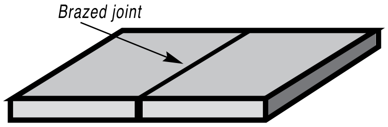
(Consider too, that lower temperatures need less heat which can be a significant cost-saving factor.)

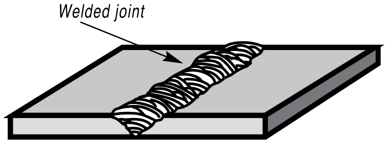
An important advantage of brazing is the ease with which it joins dissimilar metals. If you don't have to melt the base metals to join them, it doesn't matter if they have widely different melting points. You can braze steel to copper as easily as steel to steel.

Welding is a different story. You must melt the base metals to fuse them. So if you try to weld copper (melting point 1981°F/1083°C) to steel (melting point 2500°F/1370°C), you have to employ rather sophisticated, and expensive, welding techniques.

The total ease of joining dissimilar metals through conventional brazing procedures means you can select whatever metals are best suited to the function of the assembly—knowing you'll have no problem joining them no matter how widely they vary in melting temperatures.

Another advantage of a brazed joint is its good appearance. The comparison between the tiny, neat fillet of a brazed joint and the thick, irregular bead of a welded joint is like night and day.





This characteristic is especially important for joints on consumer products, where appearance is critical. A brazed joint can almost always be used *as is*, without any finishing operations needed. And that too is a money-saver.

Brazing offers another significant advantage over welding in that brazing skills can usually be acquired faster than welding skills. The reason lies in the inherent difference between the two processes. A linear welded joint has to be traced with precise synchronization of heat application and deposition of filler metal. A brazed joint, on the other hand, tends to "make itself" through capillary action. (A considerable portion of the skill involved in brazing actually lies in the design and engineering of the joint.) The comparative quickness with which a brazing operator may be trained to a high degree of skill is an important cost consideration.

Finally, brazing is relatively easy to automate. The characteristics of the brazing process—broad heat applications and ease of positioning of filler metal—help eliminate the potential for problems. There are so many ways to get heat to the joint automatically, so many forms of brazing filler metal and so many ways to deposit them, that a brazing operation can easily be automated to the extent needed for almost any level of production.

Brazing advantages

- *Joint strength*
- *Lower temperatures/lower cost*
- *Maintains integrity of base metals*
- *Dissimilar metals easily joined*
- *Good joint appearance*
- *Operator skill easily acquired*
- *Process easily automated*

Which joining method is best?

As we've indicated, when you want to make strong and permanent metal joints, your choice will generally narrow down to welding or brazing.

So, which method is best?

It depends entirely on the circumstances. The key factors in making a decision will boil down to the *size* of the parts to be joined, the *thickness* of the metal sections, *configuration* of the joint, *nature* of the base metals, and the *number* of joints to be made. Let's consider each of them.

How big is the assembly?

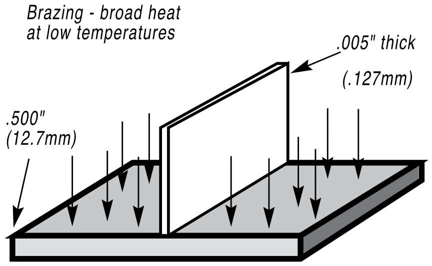
Welding is usually more suited to the joining of large assemblies than brazing. Why? Because in brazing the heat must be applied to a broad area, often to the entire assembly. And if the assembly is a large one, it's often hard to heat it to the flow point of the filler metal as the heat tends to dissipate faster than you build it up.

You don't meet this limitation in welding. The intense localized heat of welding, sometimes a drawback, becomes an advantage in joining a large assembly. So does welding's ability to trace a joint.

There's no way to establish exactly the point at which size of assembly makes one metal joining method more practical than another. There are too many factors involved. For example, if the assembly is unable to be brazed in open air (torch, induction, etc.) due to size, a furnace or dip brazing process may eliminate the size consideration. However, you can still use this rule-of-thumb as a starting point: Large assembly—weld, if the nature of the metals permits. Small assembly—braze. Medium-sized assembly—experiment.

How thick are the metal sections?

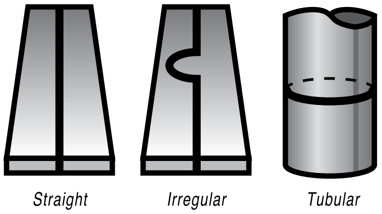
Thickness of base metal sections is an important consideration in selecting your metal joining method. If both sections are relatively thick—say .500" (12.7mm)—either welding or brazing can produce a strong joint. But if you want to make a T-joint, bonding a .005" (.127mm) thick sheet metal section to half-inch stock, for example, brazing is the better choice. The intense heat of welding is likely to burn through, or at least warp, the thin section. The broader heat and lower temperature of brazing allows you to join the sections without warpage or metal distortion.



What's the joint configuration?

Is the joint a "spot" or a "line"? A spot joint made at one point can be accomplished as easily by welding as by brazing. But a *linear* joint—all other things being equal—is more easily brazed than welded. Brazing needs no manual tracing. The filler metal is drawn through the joint area by capillary action, which works with equal ease on any joint configuration.

Brazing joins all these configurations with equal ease.



What metals are you joining?

Suppose you're planning a two-section metal assembly. You want high electrical conductivity in one section, high strength and corrosion resistance in the other. You want to use copper for conductivity, and stainless for strength and corrosion resistance.

Welding this assembly will present problems. As we've seen, you have to melt both metals to fuse them. But stainless melts at a much higher temperature than copper. The copper would completely melt and flow off before the stainless came anywhere close to its melting temperature.

Brazing these dissimilar metals offers no such obstacle. All you have to do is select a brazing filler metal that is metallurgically compatible with both base metals and has a melting point lower than that of the two. You get a strong joint, with minimal alteration of the properties of the metals.

The point to remember is that brazing joins metals *without melting them*, by metallurgically bonding at their interfaces. The integrity and properties of each metal in the brazed assembly are retained with minimal change.

If you plan to join dissimilar metals—think brazing.

How many assemblies do you need?

For a single assembly, or a few assemblies, your choice between welding and brazing will depend largely on the factors discussed earlier—size of parts, thickness of sections, joint configurations, and nature of base metals. Whether you braze or weld, you'll probably do the job manually. But when your production needs run into the hundreds, or thousands (or hundreds of thousands), production techniques and cost factors become decisive.

Which method is best—for *production* metal joining?

Both methods can be automated. But they differ greatly in flexibility of automation. Welding tends to be an all-or-nothing proposition. You weld manually, one-at-a-time, or you install expensive, sophisticated equipment to handle very large runs of identical assemblies. There's seldom a practical in-between.

Brazing is just the opposite. You can braze "one-at-a-time" manually, of course. But you can easily introduce simple production techniques to speed up the joining of several hundred assemblies. As an example, many assemblies, pre-fluxed and bearing preplaced lengths of filler metal, can be simultaneously heated and brazed in a furnace. When you get into larger runs, it may become practical to rig up a conveyor which can run the assemblies past banks of heating torches and brazing filler metal can be applied to the joint in a pre-measured amount. And there are endless "in-between" possibilities, a good many of which you can accomplish with relatively inexpensive production devices.

The point to keep in mind is that brazing is flexible. You can automate it on a step-by-step basis, at each step matching your automation investment to your production requirements.

Welding vs. brazing considerations

- *Size of assembly?*
- *Thickness of base metal sections?*
- *Spot or line joint?*
- *Metals being joined?*
- *Final assembly quantity needed?*

Section 1: The Idea of Brazing

When do you think brazing?

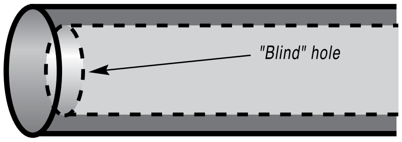
Brazing as a means to make a part.

So far, we've been talking about brazing as a way of joining two or more metals into a permanent assembly. And we've limited our discussion to the situations where you have a metal *assembly* in mind from the outset, from initial product concept through finished piece.

Now let's discuss brazing from a very different point of view. Think about the parts your company fabricates, and consider whether any of those parts now made as *monolithic units*, might not be made more efficiently as *brazed assemblies*.

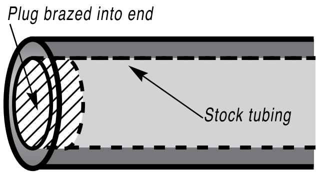
Consider this real-life story...

A company was fabricating thousands of small, closed-end metal cylinders. The part looked like this:



For years the cylinders were machined out of solid bar stock, with considerable labor required to drill and bore the blind holes. Finally, someone suggested that the cylinder was actually *two* parts—a tube and a plug.

Now the cylinders are made as *assemblies*—bar stock cut-offs brazed into lengths of stock tubing:



The assembly is a lot less expensive to make than the machined part—and it works just as well.

Think brazing at the beginning.

The time to consider brazing is at the beginning, when you're first planning or designing any metal component.

Ask yourself if the part should be made as a single unit, or if it can better be made as an assembly of simple components.

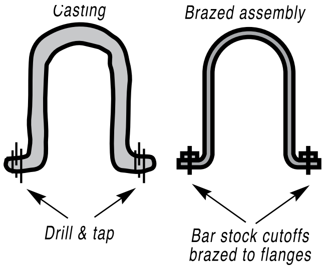
The "assembly" approach may help you eliminate expensive casting, forging and machining operations. It may save materials. It may enable you to use low-cost stock forms—sheet, tube, rod, stampings or extrusions. It will almost invariably be lighter in weight than the monolithic part, and will probably work better as the metals in the assembly can be selected to match their functions.

Let's look at some typical metal "parts." First we'll see how they're made by conventional casting, forging and machining methods. And then we'll see how they could be made better and more economically as brazed assemblies.

From casting to sheet metal.

You're designing a housing, with threaded holes in the flange. You could make it as a casting. But consider instead making it as a brazed assembly, joining bar stock sections to a sheet metal deep draw:

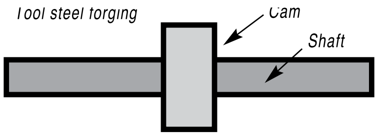
The brazed assembly works just as well as the casting. And it's a lot cheaper to make, because you're putting the thickness only where you really need it—in the flange and not the shell. You save weight, materials and labor.



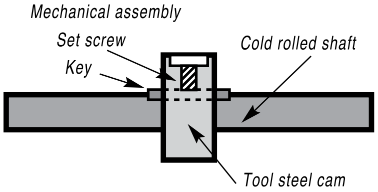
From forging to brazing.

You're planning a part—a hardened cam on a steel camshaft. Should you machine the unit out of a solid bar of tool steel? That's a lot of lathe chips. Perhaps forge the piece, and then finish-machine it?

Still a lot of work. After hardening, the cam has to be drawn and the shaft ends annealed. How about making the cam and shaft *separately*—and then join them mechanically as an *assembly*?

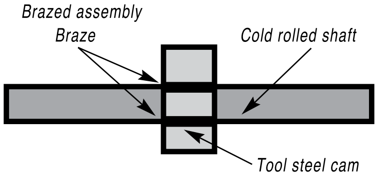


You're on the right track. By substituting cold rolled for tool steel in the shaft, you're saving on material cost. But machining is still somewhat involved, and a locking device, such as a set screw, is subject to loosening under vibration.



Now try the "assembly" approach again, but this time use a brazed joint instead of a mechanical one.

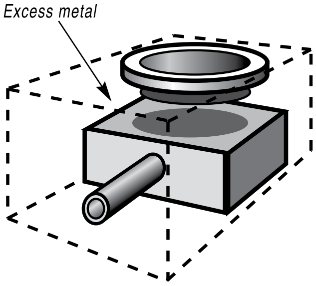
Simplest of all. No keyway, no key, no set screw. Minimum material, minimum labor—and a strong, permanent, vibration-proof bond.



The awkward elbow.

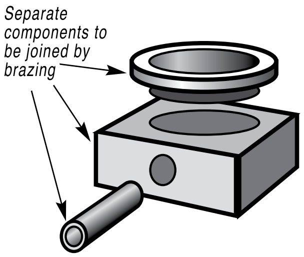
Extensions or projections on metal parts require excessive material (expensive!), and then a lot of work to machine away the unwanted metal (twice as expensive!). Consider what happens when you make an elbow-shaped part from solid stock...

You're paying for metal you don't



want, and the labor of getting rid of it. There's an easier way. Make the "part" as a brazed assembly, joining together standard tubing and bar stock components:

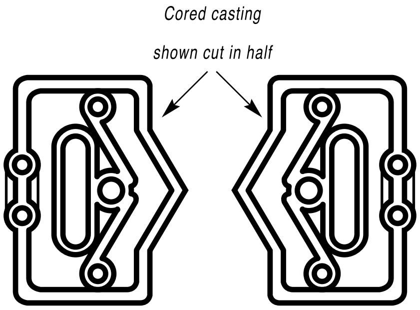
The assembly will be just as strong as the machined part. And you'll save materials, labor—and weight. (The more awkward and complex the extension, the more you'll save.)



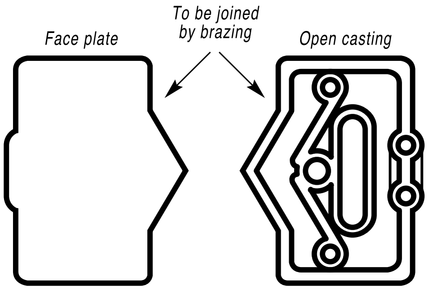
From hard to easy.

You have to design a leak-tight component, with complex configuration. You can plan it as a cored casting…

It will be leak-tight, but a cored casting is an expensive one. An open casting is a lot cheaper to make. So why not make it that way?



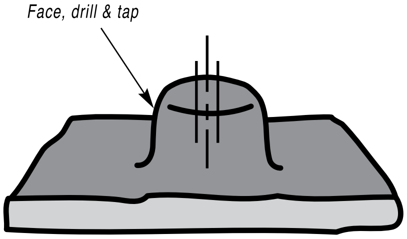
By using brazing, you've replaced the complex cored casting with a simple open casting—and a metal stamping. Machining is easier, and brazing's capillary action assures you of a leak-tight bond.



From casting to stock parts.

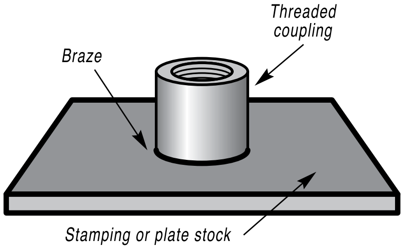
Let's say you're designing a base plate with a threaded coupling. You can make it in one piece as a casting…

Material cost is low, but material *choice* is limited. Weight is excessive, machining extensive, and the finished part may be weak and brittle.



Consider making the "part" as a brazed assembly of stock elements…

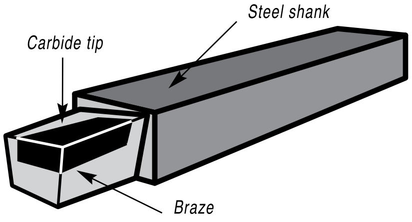
Machining is minimal—the base plate is a stamping and the coupling a screw machine part. Weight is down to the bone, too, because the thickness is only where it's needed, in the threaded coupling. Material can be matched to function. And the assembly will undoubtedly be stronger than the casting.



Two metals are better than one.

The ability of brazing to join dissimilar metals is helpful in many applications, but in some instances it's quite critical. A classic example is the carbide metal-cutting tool. The tool could be made entirely of carbide. But carbide is expensive. What's more, though carbide is fine for the cutting tip, you don't really want to use it for the tool shank. It's too hard and brittle to withstand shock.

Brazing solves the problem…



By brazing, you've reduced material cost—obviously. But even more—you're now using metals perfectly suited to their functions. Hard carbide at the cutting edge, and shock-resistant tool steel for the shank.

Freedom for the designer.

We started this section with a question: "When do you think brazing?" And we've indicated, through just a few of the many possible examples, that you think brazing at the beginning—at the design stage.

The fact is—brazing liberates the designer. It enables him to design for function, for light weight, for selective use of metals, and for production economy. The designer who's fully aware of the possibilities of brazing thinks less and less in terms of castings, forgings and parts machined from solid metal. He thinks more and more in terms of brazed assemblies, which combine plate or sheet stock, standard tubing and bar, stampings and screw machine parts.

Assemblies based on the use of such elements are generally lighter in weight, less expensive to fabricate, and at least equal in performance to metal parts made as monolithic units.

The principles of joint design.

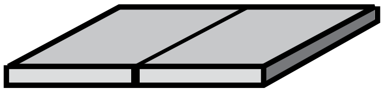
Types of brazed joints.

What type of brazed joint should you design?

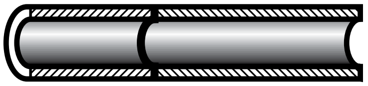
There are many kinds of joints. But our problem is simplified by the fact that there are only *two* basic types—the butt and the lap. The rest are essentially modifications of these two.

Let's look first at the *butt joint*, both for flat and tubular parts.

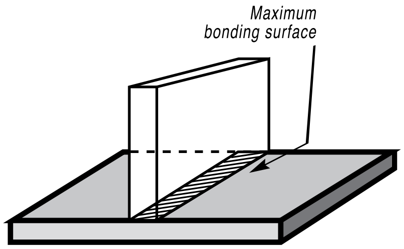
Butt joint - flat parts



Butt joint - tubular parts (cutaway)

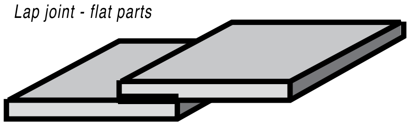


As you can see, the butt joint gives you the advantage of a single thickness at the joint. Preparation of this type of joint is usually simple, and the joint will have sufficient tensile strength for a good many applications. However, the strength of the butt joint does have limitations. It depends, in part, on the *amount of bonding surface*, and in a butt joint the bonding area can't be any larger than the cross-section of the thinner member.

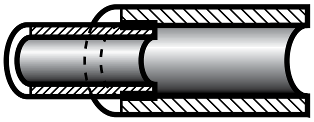


Now let's compare this with the *lap joint*, both for flat and tubular parts.

Lap joint - flat parts

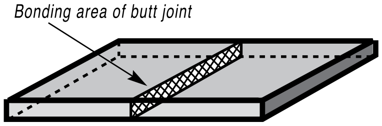


Lap joint - tubular parts (cutaway)

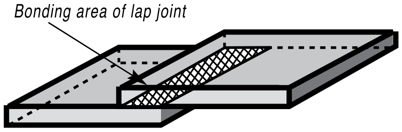


The first thing you'll notice is that, for a given thickness of base metals, the *bonding area* of the lap joint can be larger than that of the butt joint—and usually is. With larger bonding areas, lap joints can usually carry larger loads.

Bonding area of butt joint



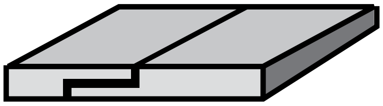
Bonding area of lap joint



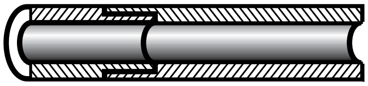
The lap joint gives you a double thickness at the joint, but in many applications (plumbing connections, for example) the double thickness is not objectionable. And the lap joint is generally self-supporting during the brazing process. Resting one flat member on the other is usually enough to maintain a uniform joint clearance. And, in tubular joints, nesting one tube inside the other holds them in proper alignment for brazing.

However—suppose you want a joint that has the advantages of both types; single thickness at the joint combined with maximum tensile strength. You can get this combination by designing the joint as a *butt-lap* joint.

Butt-lap joint - flat parts



Butt-lap joint - tubular parts (cutaway)



True, the butt-lap is usually a little more work to prepare than straight butt or lap, but the extra work can pay off. You wind up with a single-thickness joint of maximum strength. And the joint is usually self-supporting when assembled for brazing.

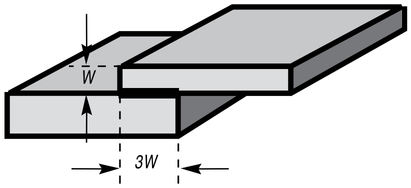
Figuring the proper length of lap.

Obviously, you don't have to calculate the bonding area of a butt joint. It will be the cross-section of the thinner member—and that's that.

But lap joints are often variable. Their length can be increased or decreased. How long should a lap joint be?

The rule of thumb is to design the lap joint to be *three times as long* as the thickness of the thinner joint member.

Length of lap



A longer lap may waste brazing filler metal and use more base metal material than is really needed, without a corresponding increase in joint strength. And a shorter lap will lower the strength of the joint. For most applications, you're on safe ground with the "rule of three."

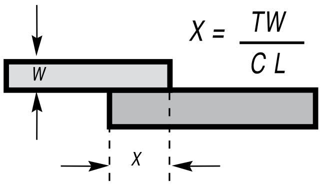
More specifically, if you know the approximate tensile strengths of the base members, the lap length required for optimum joint strength in a silver brazed joint is as follows:

Tensile strength of weakest member		**Lap length = factor x W (W = thickness of weakest member)**
35,000 psi	- 241.3 MPa	2 x W
60,000 psi	- 413.7 MPa	3 x W
100,000 psi	- 689.5 MPa	5 x W
130,000 psi	- 896.3 MPa	6 x W
175,000 psi	-1,206.6 MPa	8 x W

NOTE: psi x 6.8948 = 1 MPa

If you have a great many identical assemblies to braze, or if the joint strength is critical, it will help to figure the length of lap more exactly, to gain maximum strength with minimum use of brazing materials. The formulas given below will help you calculate the optimum lap length for flat and for tubular joints.

Figuring length of lap for flat joints.



$$X = \frac{TW}{CL}$$

X = Length of lap
T = Tensile strength of weakest member
W = Thickness of weakest member
C = Joint integrity factor of .8
L = Shear strength of brazed filler metal

Let's see how this formula works, using an example.

Problem: *What length of lap do you need to join .050″ annealed Monel sheet to a metal of equal or greater strength?*
Solution:
C = .8
T = 70,000 psi (annealed Monel sheet)
W = .050″
L = 25,000 psi (Typical shear strength for silver brazing filler metals)

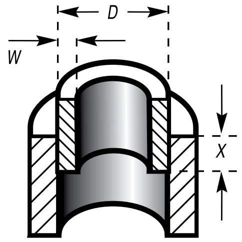
$$X = \frac{70{,}000 \times .050}{.8 \times 25{,}000} = .18'' \text{ lap length}$$

Problem in metric: *What length of lap do you need to join 1.27 mm annealed Monel sheet to a metal of equal or greater strength?*
Solution:
C = .8
T = 482.63 MPa (annealed Monel sheet)
W = 1.27 mm
L = 172.37 MPa (Typical shear strength for silver brazing filler metals)

$$X = \frac{482.63 \times 1.27}{.8 \times 172.37}$$

X = 4.5 mm (length of lap)

Figuring length of lap for tubular joints.



$$X = \frac{W\ (D\text{-}W)\ T}{C\ L\ D}$$

X = Length of lap area
W = Wall thickness of weakest member
D = Diameter of lap area
T = Tensile strength of weakest member
C = Joint integrity factor of .8
L = Shear strength of brazed filler metal

Again, an example will serve to illustrate the use of this formula.
Problem: *What length of lap do you need to join 3⁄4″ O.D. copper tubing (wall thickness .064″) to 3⁄4″ I.D. steel tubing?*
Solution:
W = .064″
D = .750″
C = .8
T = 33,000 psi (annealed copper)
L = 25,000 psi (a typical value)

$$X = \frac{.064 \times (.75 - .064) \times 33{,}000}{.8 \times .75 \times 25{,}000}$$

X = .097″ (length of lap)

Problem in metric: *What length of lap do you need to join 19.05 mm O.D. copper tubing (wall thickness 1.626 mm) to 19.05 mm I.D. steel tubing?*
Solution:
W = 1.626 mm
D = 19.05 mm
C = .8
T = 227.53 MPa (annealed copper)
L = 172.37 MPa (a typical value)

$$X = \frac{1.626 \times (19.05 - 1.626) \times 227.53}{.8 \times 19.05 \times 172.37}$$

X = 2.45 mm (length of lap)

Designing to distribute stress.

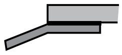
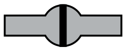
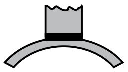
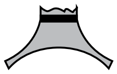
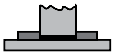
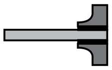
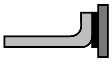
When you design a brazed joint, obviously you aim to provide at least minimum adequate strength for the given application. But in some joints, *maximum* mechanical strength may be your overriding concern.

You can help insure this degree of strength by designing the joint to prevent concentration of stress from weakening the joint.

Motto—*spread the stress.* Figure out where the greatest stress falls. Then impart flexibility to the heavier member at this point, or add strength to the weaker member.

The illustrations below suggest a number of ways to spread the stress in a brazed joint.

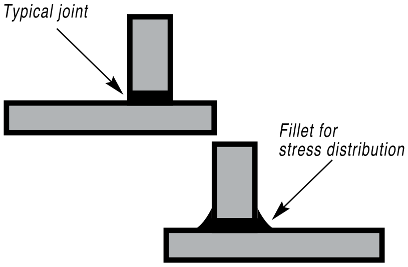
Designing to distribute stress

Problem	*Solution A*	*Solution B*
 *Stress concentrated here*	 *Light section strengthened at joint*	 *Heavy section shaped to reduce stress*
 *Stress concentrated here (butt joint)*	 *Members thickened at joint*	 *Scarf joint to increase bonding area*
 *Stress concentrated here*	 *Light section strengthened at joint*	 *Light section reinforced at joint*
 *Stress concentrated here*	 *One member redesigned to reduce stress*	 *Other member redesigned to spread stress*

To sum it up—when you're designing a joint for maximum strength, use a lap or scarf design (to increase joint area) rather than a butt, and design the parts to prevent stress from being concentrated at a single point.

There is one other technique for increasing the strength of a brazed joint, frequently effective in brazing small-part assemblies. You can create a stress-distribution *fillet*, simply by using a little more brazing filler metal than you normally would, or by using a more "sluggish" alloy.

Usually you don't want or need a fillet in a brazed joint, as it doesn't add materially to joint strength. But where it contributes to spreading joint stresses, it pays to create the fillet.



Designing for service conditions.

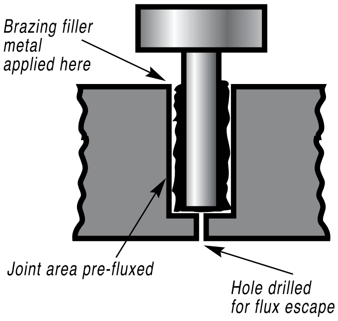
In many brazed joints, the chief requirement is strength. And we've discussed various ways of achieving joint strength. But there are frequently other service requirements which may influence the joint design or filler metal selection.

For example, you may be designing a brazed assembly that needs to be *electrically conductive.* A silver brazing filler metal, by virtue of its silver content, has very little tendency to increase electrical resistance across a properly-brazed joint. But you can further insure minimum resistance by using a close joint clearance, to keep the layer of filler metal as thin as possible. In addition, if strength is not a prime consideration, you can reduce length of lap. Instead of the customary "rule of three," you can reduce lap length to about 1-$^{1}/_{2}$ times the cross-section of the thinner member.

If the brazed assembly has to be *pressure-tight* against gas or liquid, a lap joint is almost a must, since it withstands greater pressure than a butt joint. And its broader bonding area reduces any chance of leakage.

Another consideration in designing a joint to be leak proof is to vent the assembly. Providing a vent during the brazing process allows expanding air or gases to escape as the molten filler metal flows into the joint. Venting the assembly also prevents entrapment of flux in the joint. Avoiding entrapped gases or flux reduce the potential for leak paths.

If possible, the assembly should be self-venting. Since flux is designed to be displaced by molten filler metal entering a joint, there should be no sharp corners or blind holes to cause flux entrapment. The joint should be designed so that the flux is pushed completely out of the joint by the filler metal. Where this is not possible, small holes may be drilled into the blind spots to allow flux escape. The joint is completed when molten filler metal appears at the outside surface of these drilled holes.



To maximize *corrosion-resistance* of a joint, select a brazing filler metal containing such elements as silver, gold or palladium, which are inherently corrosion-resistant. Keep joint clearances close and use a minimum amount of filler metal, so that the finished joint will expose only a fine line of brazing filler metal to the atmosphere.

These are but a few examples of service requirements that may be demanded of your brazed assembly. As you can see both the joint design and filler metal selection must be considered.

Fortunately, there are many filler metals and fluxes available to you—in a wide range of compositions, properties and melting temperatures. The selector charts that appear later in this book can help you choose filler metals and fluxes that best meet the service requirements of the joints you design.

The Technical Services Department at Lucas-Milhaupt is available to help answer any questions you may have with regard to your specific brazing application, joint design and/or filler metal selection.

The six basic steps in brazing.

The importance of correct procedures.

We've said that a brazed joint "makes itself"—or that capillary action, more than operator skill, insures the distribution of the filler metal into the joint. The real skill lies in the design and engineering of the joint. But even a properly-designed joint can turn out imperfectly if correct brazing procedures are not followed.

These procedures boil down to six basic steps. They are generally simple to perform (some may take only a few seconds), but none of them should be omitted from your brazing operation if you want to end up with sound, strong, neat-appearing joints.

For the sake of simplicity, we'll discuss these six steps mainly in terms of "manual brazing," that is, brazing with hand-held torch and hand-fed filler metal. But everything said about manual brazing applies as well to mass production brazing. The same steps must be taken, although they may be performed in a different manner.

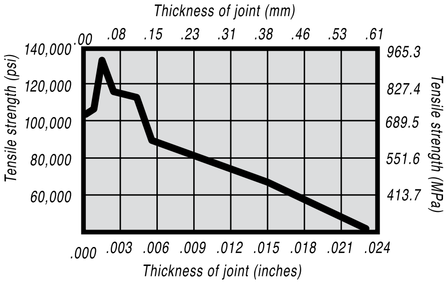
Step 1: Good fit and proper clearances.

Brazing, as we've seen, uses the principle of capillary action to distribute the molten filler metal between the surfaces of the base metals. Therefore, during the brazing operation, you should take care to maintain a clearance between the base metals to allow capillary action to work most effectively.

This means, in almost all cases—a *close clearance.*

The following chart is based on brazing butt joints of stainless steel, using Easy-Flo® filler metal. It shows how the tensile strength of the brazed joint varies with the amount of clearance between the parts being joined.

Effect of joint thickness on tensile strength



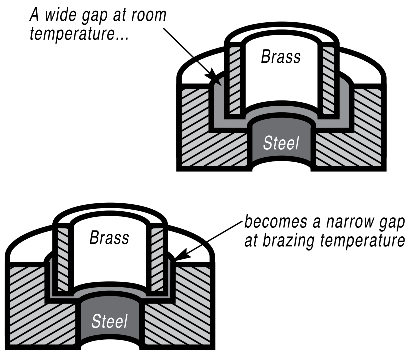
Note that the strongest joint (135,000 psi/930.8 MPa) is achieved when the joint clearance is .0015" (.038mm.) When the clearance is narrower than this, it's harder for the filler metal to distribute itself adequately throughout the entire joint—and joint strength is reduced. Conversely, if the gap is *wider* than necessary, the strength of the joint will be reduced almost to that of the filler metal itself. Also, capillary action is reduced, so the filler metal may fail to fill the joint completely—again lowering joint strength.

So the ideal clearance for a brazed joint, in the example above, is in the neighborhood of .0015" (.038mm.) But in ordinary day-to-day brazing, you don't have to be this precise to get a sufficiently strong joint. Capillary action operates over a *range* of clearances, so you get a certain amount of leeway. Look at the chart again, and see that clearances ranging from .001" to .005" (.025 mm to .127 mm) still produce joints of 100,000 psi (689.5 MPa) tensile strength.

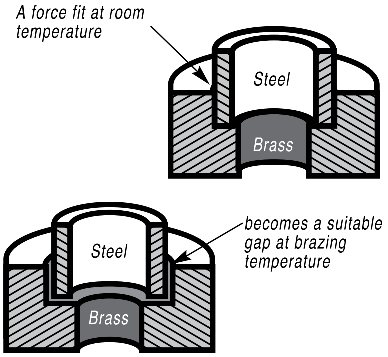
Translated into everyday shop practice—an easy slip fit will give you a perfectly adequate brazed joint between two tubular parts. And if you're joining two flat parts, you can simply rest one on top of the other. The metal-to-metal contact is all the clearance you'll usually need, since the average "mill finish" of metals provides enough surface roughness to create capillary "paths" for the flow of molten filler metal. (Highly polished surfaces, on the other hand, tend to restrict filler metal flow.)

However, there's a special factor you should consider carefully in planning your joint clearances. Brazed joints are made at *brazing* temperatures, not at room temperature. So you must take into account the "coefficient of thermal expansion" of the metals being joined. This is particularly true of tubular assemblies in which dissimilar metals are joined.

As an example, let's say you're brazing a brass bushing into a steel sleeve. Brass expands, when heated, more than steel. So if you machine the parts to have a room temperature clearance of .002"-.003" (.051 mm-.076 mm), by the time you've heated the parts to brazing temperatures the gap may have closed completely! The answer? Allow a greater *initial* clearance, so that the gap at brazing temperature will be about .002"-.003" (.051 mm-.076 mm.)



Of course, the same principle holds in reverse. If the outer part is brass and the inner part steel, you can start with virtually a light force fit at room temperature. By the time you reach brazing temperature, the more rapid expansion of the brass creates a suitable clearance.



Comparisons of Materials: Coefficient of Thermal Expansion[a]

Material	10^{-6} in./in.*/°F		10^{-5} in./in.*/°C	
	High	Low	High	Low
Zinc & its Alloys[c]	19.3	10.8	3.5	1.9
Lead & its Alloys[c]	16.3	14.4	2.9	2.6
Magnesium Alloys[b]	16	14	2.8	2.5
Aluminum & its Alloys[c]	13.7	11.7	2.5	2.1
Tin & its Alloys[c]	13	—	2.3	—
Tin & Aluminum Brasses[c]	11.8	10.3	2.1	1.8
Plain & Leaded Brasses[c]	11.6	10	2.1	1.8
Silver[c]	10.9	—	2.0	—
Cr-Ni-Fe Superalloys[d]	10.5	9.2	1.9	1.7
Heat Resistant Alloys (cast)[d]	10.5	6.4	1.9	1.1
Nodular or Ductile Irons (cast)[c]	10.4	6.6	1.9	1.2
Stainless Steels (cast)[d]	10.4	6.4	1.9	1.1
Tin Bronzes (cast)[c]	10.3	10	1.8	1.8
Austenitic Stainless Steels[c]	10.2	9	1.8	1.6
Phosphor Silicon Bronzes[c]	10.2	9.6	1.8	1.7
Coppers[c]	9.8	—	1.8	—
Nickel-Base Superalloys[d]	9.8	7.7	1.8	1.4
Aluminum Bronzes (cast)[c]	9.5	9	1.7	1.6
Cobalt-Base Superalloys[d]	9.4	6.8	1.7	1.2
Beryllium Copper[c]	9.3	—	1.7	—
Cupro-Nickels & Nickel Silvers[c]	9.5	9	1.7	1.6
Nickel & its Alloys[d]	9.2	6.8	1.7	1.2
Cr-Ni-Co-Fe Superalloys[d]	9.1	8	1.6	1.4
Alloy Steels[d]	8.6	6.3	1.5	1.1
Carbon Free-Cutting Steels[d]	8.4	8.1	1.5	1.5
Alloy Steels (cast)[d]	8.3	8	1.5	1.4
Age Hardenable Stainless Steels[c]	8.2	5.5	1.5	1.0
Gold[c]	7.9	—	1.4	—
High Temperature Steels[d]	7.9	6.3	1.4	1.1
Ultra High Strength Steels[d]	7.6	5.7	1.4	1.0
Malleable Irons[c]	7.5	5.9	1.3	1.1
Titanium Carbide Cermet[d]	7.5	4.3	1.3	.8
Wrought Irons[c]	7.4	—	1.3	—
Titanium & its Alloys[d]	7.1	4.9	1.3	.9
Cobalt[d]	6.8	—	1.2	—
Martensitic Stainless Steels[c]	6.5	5.5	1.2	1.0
Nitriding Steels[d]	6.5	—	1.2	—
Palladium[c]	6.5	—	1.2	—
Beryllium[b]	6.4	—	1.1	—
Chromium Carbide Cermet[c]	6.3	5.8	1.1	1.0
Thorium[b]	6.2	—	1.1	—
Ferritic Stainless Steels[c]	6	5.8	1.1	1.0
Gray Irons (cast)[c]	6	—	1.1	—
Beryllium Carbide[d]	5.8	—	1.0	—
Low Expansion Nickel Alloys[c]	5.5	1.5	1.0	.3
Beryllia & Thoria[e]	5.3	—	.9	—
Alumina Cermets[d]	5.2	4.7	.9	.8
Molybdenum Disilicide[c]	5.1	—	.9	—
Ruthenium[b]	5.1	—	.9	—
Platinum[c]	4.9	—	.9	—
Vanadium[b]	4.8	—	.9	—
Rhodium[b]	4.6	—	.8	—
Tantalum Carbide[d]	4.6	—	.8	—
Boron Nitride[d]	4.3	—	.8	—
Columbium & its Alloys	4.1	3.8	.7	.68
Titanium Carbide[d]	4.1	—	.7	—
Steatite[c]	4	3.3	.7	.6
Tungsten Carbide Cermet[c] .. 3.9	2.5	.7	.4	
Iridium[b]	3.8	—	.7	—
Alumina Ceramics[c]	3.7	3.1	.7	.6
Zirconium Carbide[d]	3.7	—	.7	—
Osmium and Tantalum[b]	3.6	—	.6	—
Zirconium & its Alloys[b]	3.6	3.1	.6	.55
Hafnium[b]	3.4	—	.6	—
Zirconia[e]	3.1	—	.6	—
Molybdenum & its Alloys	3.1	2.7	.6	.5
Silicon Carbide[e]	2.4	2.2	.4	.39
Tungsten[b]	2.2	—	.4	—
Electrical Ceramics[c]	2	—	.4	—
Zircon[c]	1.8	1.3	.3	.2
Boron Carbide[e]	1.7	—	.3	—
Carbon and Graphite[c]	1.5	1.3	.3	.2

[a] Values represent high and low sides of a range of *typical* values. (* or mm/mm)

[b] Value at room temperature only.

[c] Value for a temperature range between room temperature and 212-750° F/100-390° C.

[d] Value for a temperature range between room temperature and 1000-1800° F/540-980° C.

[e] Value for a temperature range between room temperature and 2200-2875° F/1205-1580° C.

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How much allowance should you make for expansion and contraction? It depends on the nature and sizes of the metals being joined and the configuration of the joint itself. Although there are many variables involved in pin-pointing exact clearance tolerances for each situation, keep in mind the principle involved—different metals expand at different rates when heated. To help you in planning proper clearances in brazing dissimilar metals, the chart on the opposite page furnishes the coefficient of thermal expansion for a variety of metals and alloys.

Step 2: Cleaning the metals.

Capillary action will work properly only when the surfaces of the metals are clean. If they are "contaminated"—coated with oil, grease, rust, scale or just plain dirt—those contaminants have to be removed. If they remain, they will form a barrier between the base metal surfaces and the brazing materials. An oily base metal, for example, will repel the flux, leaving bare spots that oxidize under heat and result in voids. Oil and grease will carbonize when heated, forming a film over which the filler metal will not flow. And brazing filler metal won't bond to a rusty surface.

Cleaning the metal parts is seldom a complicated job, but it has to be done in the right sequence. Oil and grease should be removed first, because an acid pickle solution aimed to remove rust and scale won't work on a greasy surface. (If you try to remove rust or scale by abrasive cleaning, before getting rid of the oil, you'll wind up scrubbing the oil, as well as fine abrasive powder, more deeply into the surface.)

Start by getting rid of oil and grease. In most cases you can do it very easily either by dipping the parts into a suitable degreasing solvent, by vapor degreasing, or by alkaline or aqueous cleaning.

If the metal surfaces are coated with oxide or scale, you can remove those contaminants chemically or mechanically. For chemical removal, use an acid pickle treatment, making sure that the chemicals are compatible with the base metals being cleaned, and that no acid traces remain in crevices or blind holes. Mechanical removal calls for abrasive cleaning. Particularly in repair brazing, where parts may be very dirty or heavily rusted, you can speed the cleaning process by using emery cloth, grinding wheel, or file or grit blast, followed by a rinsing operation.

Once the parts are thoroughly clean, it's a good idea to flux and braze as soon as possible. That way, there's the least chance for recontamination of surfaces by factory dust or body oils deposited through handling.

Step 3: Fluxing the parts.

Flux is a chemical compound applied to the joint surfaces before brazing. Its use is essential in the brazing process (with a few exceptions noted later.) The reason? Heating a metal surface accelerates the formation of oxides, the result of chemical combination between the hot metal and oxygen in the air. These oxides must be prevented from forming or they'll inhibit the brazing filler metal from wetting and bonding to the surfaces. A coating of flux on the joint area, however, will shield the surfaces from the air, preventing oxide formation. And the flux will also dissolve and absorb any oxides that form during heating or that were not completely removed in the cleaning process.

How do you apply the flux to the joint? Any way you can, as long as you cover the surfaces completely. Since flux is conventionally made in a paste consistency, it's usually most convenient to brush it on. But as production quantities increase, it may be more efficient to apply the flux by dipping—or dispensing a pre-measured deposit of high viscosity dispensable flux from an applicator gun. Why dispensable flux? Many companies find the repeatable deposit size improves joint consistency, and because typically less flux is used, the amount of residue entering the waste stream is also reduced.

When do you flux? Typically just before brazing, if possible. That way the flux has least chance to dry out and flake off, or get knocked off the parts in handling.

Which flux do you use? Choose the one formulated for the specific metals, temperatures and conditions of your brazing application. There are fluxes formulated for practically every need; for example—fluxes for brazing at very high temperatures (in the 2000°F/1093°C area), fluxes for metals with refractory oxides, fluxes for long heating cycles, and fluxes for dispensing by automated machines. Fortunately, your inventory problem is considerably simplified by the availability of *general-purpose* fluxes, such as Lucas-Milhaupt's Handy® Flux, which is suitable for most typical brazing jobs. (See page 40 for a chart of Lucas-Milhaupt fluxes.) Our technical representative can answer any questions you may have and assist you in your choice.

How much flux do you use? Enough to last throughout the entire heating cycle. Keep in mind that the larger and heavier the pieces brazed, the longer the heating cycle will take—so use *more* flux. (Lighter pieces, of course, heat up faster and so require less flux.)

As a general rule, *don't skimp on the flux*. It's your insurance against oxidation. Think of the flux as a sort of blotter. It absorbs oxides like a sponge absorbs water. An insufficient amount of flux will quickly become saturated and lose its effectiveness. A flux that absorbs less oxides not only insures a better joint than a totally saturated flux, but it is a lot easier to wash off after the brazed joint is completed.

Flux can also act as a *temperature indicator*, minimizing the chance of overheating the parts. Lucas-Milhaupt's Handy Flux, for example, becomes completely clear and active at 1100°F/593°C. At this temperature, it looks like water and reveals the bright metal surface underneath—telling you that the base metal is just about hot enough to melt the brazing filler metal.

Handy Flux as a temperature indicator

Temp.	Appearance of flux
212°F (100°C)	Water boils off.
600°F (315°C)	Flux becomes white and slightly puffy, and starts to "work."
800°F (425°C)	Flux lies against surface and has a milky appearance.
1100°F (593°C)	Flux is completely clear and active, looks like water. Bright metal surface is visible underneath. At this point, test the temperature by touching brazing filler metal to base metal. If brazing filler metal melts, assembly is at proper temperature for brazing.

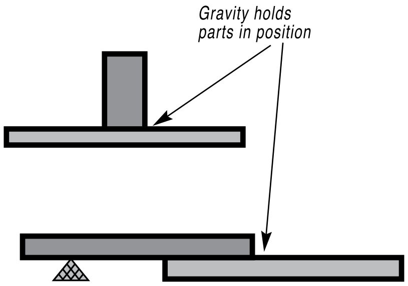
We've said that fluxing is an essential step in the brazing operation. This is generally true, yet there are a few exceptions to the rule. You can join copper to copper without flux, by using a brazing filler metal specially formulated for the job, such as Lucas-Milhaupt's Sil-Fos® or Fos-Flo®. (The phosphorus in these alloys acts as a fluxing agent on copper.)

And you can often omit fluxing if you're going to braze the assembly in a controlled atmosphere. A controlled atmosphere is a gaseous mixture contained in an enclosed space, usually a brazing furnace. The atmosphere (such as hydrogen, nitrogen or dissociated ammonia) completely envelops the assemblies and, by excluding oxygen, prevents oxidation. Even in controlled atmosphere brazing, however you may find that a small amount of flux improves the wetting action of the brazing filler metal.

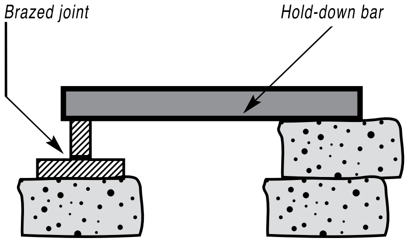
Step 4: Assembly for brazing.

The parts of the assembly are cleaned and fluxed. Now you have to hold them in position for brazing. And you want to be sure they remain in correct alignment during the heating and cooling cycles, so that capillary action can do its job.

If the shape and weight of the parts permit, the simplest way to hold them together is by gravity.

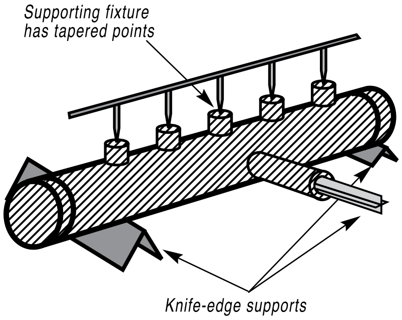


Or you can give gravity a helping hand by adding additional weight.



If you have a number of assemblies to braze and their configuration is too complex for self-support or clamping, it may be a good idea to use a brazing support fixture.

In planning such a fixture, design it for the least possible mass, and the least contact with the parts of the assembly. (A cumbersome fixture that contacts the assembly broadly will conduct heat away from the joint area.) Use *pin-point* and *knife-edge* design to reduce contact to the minimum.



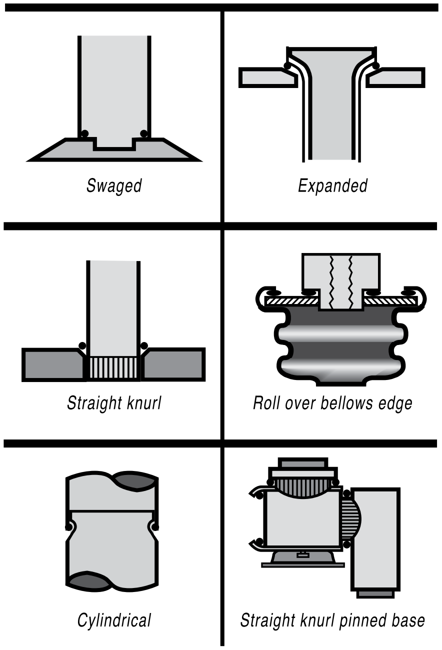
Try to use materials in your fixture that are poor heat conductors, such as stainless steel, Inconel or ceramics. Since these are poor conductors, they draw the least heat away from the joint. Choose materials with compatible expansion rates so you won't get alterations in assembly alignment during the heating cycle.

However, if you're planning to braze hundreds of identical assemblies, then you should think in terms of designing the parts themselves for *self-support* during the brazing process.

At the initial planning stage, design mechanical devices that will accomplish this purpose, and that can be incorporated in the fabricating operation. Typical devices include crimping, interlocking seams, swaging, peening, riveting, pinning, dimpling or knurling.

Sharp corners should be minimized in these mechanically held assemblies, as such corners can impede capillary action. Corners should be slightly rounded to aid the flow of filler metal.

Dot indicates where brazing filler metal will be applied



Swaged

Expanded

Straight knurl

Roll over bellows edge

Cylindrical

Straight knurl pinned base

The *simplest* mechanical holding device is the best, since its only function is to hold the parts together while the permanent joint is made by brazing.

Step 5: Brazing the assembly.

The fifth step is the actual accomplishment of the brazing joint. It involves heating the assembly to brazing temperature, and flowing the filler metal through the joint.

First, the heating process. As we've seen in brazing, you apply heat broadly to the base metals. If you're brazing a small assembly, you may heat the entire assembly to the flow point of the brazing filler metal. If you're brazing a large assembly, you heat a broad area around the joint. The heating method most commonly used in brazing a single assembly is the hand held torch. A variety of fuels are available—natural gas, acetylene, propane, propylene, etc., combusted with either oxygen or air. (Most popular is still the oxy/acetylene mixture.)

All you have to keep in mind is that both metals in the assembly should be heated as uniformly as possible so they reach brazing temperature at the same time. When joining a heavy section to a thin section, the "splash-off" of the flame may be sufficient to heat the thin part. Keep the torch moving at all times and do not heat the braze area directly. When joining heavy sections, the flux may become transparent—which is at 1100°F (593°C)—before the full assembly is hot enough to receive the filler metal.

Some metals are good conductors—and consequently carry off heat faster into cooler areas. Others are poor conductors and tend to retain heat and overheat readily. The good conductors will need more heat than the poor conductors, simply because they dissipate the heat more rapidly.

In all cases, your best insurance against uneven heating is to keep a watchful eye on the flux. If the flux changes in appearance *uniformly*, the parts are being heated evenly, regardless of the difference in their mass or conductivity.

You've heated the assembly to brazing temperature. Now you are ready to deposit the filler metal.

In manual brazing, all this involves is carefully holding the rod or wire against the joint area. The heated assembly will melt off a portion of the filler metal, which will instantly be drawn by capillary action throughout the entire joint area.

You may want to add some flux to the end of the filler metal rod—about 2" to 3" (51 mm to 76 mm)—to improve the flow. This can be accomplished by either brushing on or dipping the rod in flux. On larger parts requiring longer heating time, or where the flux has become saturated with much oxide, the addition of fresh flux on the filler metal will improve the flow and penetration of the filler metal into the joint area.

However, there is one small precaution to observe. Molten brazing filler metal tends to flow toward areas of higher temperature. In the heated assembly, the outer base metal surfaces may be slightly hotter than the interior joint surfaces. So take care to deposit the filler metal immediately adjacent to the joint. If you deposit it

Safety in Brazing

In brazing, there is always the possibility of dangerous fumes and gases rising from base metal coatings, zinc and cadmium-bearing filler metals, and from fluorides in fluxes. The following well-tested precautions should be followed to guard against any hazard from these fumes.

1. *Ventilate confined areas.* Use ventilating fans and exhaust hoods to carry all fumes and gases away from work, and air supplied respirators as required.

2. *Clean base metals thoroughly.* A surface contaminant of unknown composition on base metals may add to fume hazard and may cause a too-rapid breakdown of flux, leading to overheating and fuming.

3. *Use sufficient flux.* Flux protects base metals and filler metal during the heating cycle. Full flux coverage reduces fuming. Also, consult your SDS regarding specific hazards associated with brazing flux.

4. *Heat metals broadly.* Heat the base metals broadly and uniformly. Intense localized heating uses up flux, increases danger of fuming. Apply heat only to base metals, not to filler metal. (Direct flame on filler metal causes overheating and fuming.)

5. *Know your base metals.* A cadmium coating on a base metal will volatilize and produce toxic fume during heating. Zinc coatings (galvanized) will also fume when heated. Learn to recognize these coatings. It is recommended that they be removed before parts are heated for brazing.

6. *Know your filler metals.* Be especially careful not to overheat assembly when using filler metals that contain cadmium. Consult Pages 34-37 or the Safety Data Sheet (SDS) for maximum recommended brazing temperatures of a specific filler metal. The filler metal carries a warning label. Be sure to look for it and follow the instructions carefully.

(For other safety considerations, see the American National Standard Z49.1, "Safety in Welding and Cutting", published by the American Welding Society (AWS), 8669 NW 36th St., Doral, FL 33166

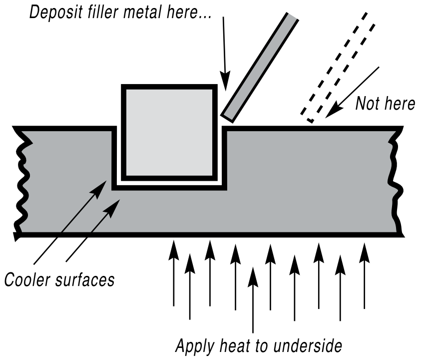
Recommended pickling solutions for post-braze removal of oxides

The pickling solutions recommended below may be used to remove oxides from areas that were not protected by flux during the brazing process. In general, they should be used after the flux residue has been removed from the brazed assembly.

Application	Formulation	Comments
Oxide removal from copper, brass, bronze, nickel silver and other copper alloys containing high percentages of copper.	10 to 25% hot sulphuric acid with 5-10% potassium dichromate added.	Pickling can be done at same time flux is removed. Will work on carbon steels, but if pickle is contaminated with copper, the copper will plate out on the steel and will have to be removed mechanically, This sulphuric pickle will remove copper or cuprous oxide stains from copper alloys. It is an oxidizing pickle, and will discolor the silver filler metal, leaving it a dull gray.
Oxide removal from irons and steels.	A 50% hydrochloric acid solution, used cold or warm. More diluted acid can be used (10-25%) at higher temperatures (140-160°F/60-70°C.)	A mixture of 1 part hydrochloric acid to 2 parts water can be used for Monel and other high nickel alloys. Pickling solution should be heated to about 180°F/80°C. Mechanical finishing is necessary for bright finishes. This HCl pickle is *not* like bright dips on nonferrous metals.
Oxide removal from stainless steels and alloys containing chromium.	20% sulphuric acid, 20% hydrochloric acid, 60% water, used at a temperature of 170-180°F (75-80°C.)	This pickle is followed directly by a 10% nitric dip, and then a clean water rinse.
	20% hydrochloric acid, 10% nitric acid, 70% water, used at about 150°F (65°C.)	This pickle is more aggressive than the sulphuric-hydrochloric mixture listed above, and will etch both the steel and the filler metal.

Note: The pickles recommended above will work with any of the standard silver filler metals, and no specific instructions are required for the individual filler metals. The phos-copper and silver-bearing phos-copper filler metals are different, and then only when used on copper without flux. In this case, a hard copper phosphate slag forms in small globules on the metal surface. Prolonged pickling in sulphuric acid will remove this slag, but a short pickle in 50% hydrochloric acid for a few minutes is more effective. When the brazed joint is to be plated or tinned, the removal of the slag is absolutely essential. A final mechanical cleaning, therefore, is advisable for work which is to be plated.

** Consult your supplier or local environmental restrictions regarding the proper product disposal information for your area.*



away from the joint, it tends to plate over the hot surfaces rather than flow into the joint. In addition, it's best to heat the side of the assembly *opposite* the point where you're going to feed the filler metal. In the example above, you heat the underside of the larger plate, so that the heat draws the filler metal down fully into the joint. (Always remember—the filler metal tends to flow toward the source of heat.)

And if you're using preforms—slugs, washers, shims or special shapes of filler metal—preplace them at the joint area *before* you heat the assembly.

Step 6: Cleaning the brazed joint.

After you've brazed the assembly, you have to clean it. And cleaning is usually a two-step operation. First—removal of the flux residues. Second—pickling to remove any oxide scale formed during the brazing process.

Flux removal is a simple, but essential operation. (Flux residues are chemically corrosive and, if not removed, could weaken certain joints.) Since most brazing fluxes are water soluble, the easiest way to remove them is to quench the assembly in hot water (120°F/50°C or hotter). Best bet is to immerse them while they're still hot, just making sure that the filler metal has solidified completely before quenching. The glass-like flux residues will usually crack and flake off. If they're a little stubborn, brush them lightly with a wire brush while the assembly is still in the hot water.

You can use more elaborate methods of removing flux as well—an ultrasonic cleaning tank to speed the action of the hot water, or live steam.

The only time you run into trouble removing flux is when you haven't used *enough* of it to begin with, or you've overheated the parts during the brazing process. Then the flux becomes totally saturated with oxides, usually turning green or black. In this case, the flux has to be removed by a mild acid solution. A 25% hydrochloric acid bath (heated to 140-160°F/60-70°C) will usually dissolve the most stubborn flux residues. Simply agitate the brazed assembly in this solution for 30 seconds to 2 minutes. No need to brush. A word of caution, however—*acid solutions are potent, so when quenching hot brazed assemblies in an acid bath, be sure to wear a face shield and gloves.*

After you've gotten rid of the flux, use a pickling solution to remove any oxides that remain on areas that were unprotected by flux during the brazing process. The best pickle to use is generally the one recommended by the manufacturer of the brazing materials you're using. (See the Lucas-Milhaupt recommendations for pickling solutions on the opposite page.)

Highly oxidizing pickling solutions, such as bright dips containing nitric acid, should be avoided if possible, as they attack the silver filler metal. If you do find it necessary to use them, keep the pickling time very short.

Once the flux and oxides are removed from the brazed assembly, further finishing operations are seldom needed. The assembly is ready for use, or for the application of an electroplated finish. In the few instances where you need an ultra-clean finish, you can get it by polishing the assembly with a fine emery cloth. If the assemblies are going to be stored for use at a later time, give them a light rust-resistant protective coating by adding a water soluble oil to the final rinse water.

Basic steps in brazing

1. *Ensure fit and clearance*
2. *Clean metal surfaces*
3. *Flux prior to brazing*
4. *Fixturing of parts*
5. *Brazing the assembly*
6. *Cleaning the new joint*

Hidden treasure in your scrap.

There's one last thing you should take into account, as part of your cleaning and finishing operations—the possible salvage value of your brazing scrap.

Brazing filler metals may contain silver, often in fairly high proportions. So does the filler metal scrap. And that silver is reclaimable at a good price.

It's hard to believe that the amount of scrap you generate in your brazing operation is large enough to warrant salvaging. But consider this true story ...

A Lucas-Milhaupt brazing representative, inquiring about scrap salvage, was told by a plant superintendent, "We don't *have* any brazing scrap. We tack the rod stubs and coil ends together and use them up."

The representative, however, noticed some brazing filler metal drippings hanging from the fixtures of a conveyorized brazing operation. He took a couple of samples for lab analysis. Some weeks later he presented the superintendent with a bright disc of pure silver. The silver had been refined from those few "worthless" drippings.

From then on, those conveyor fixtures were cleaned regularly—and every bit of scrap accumulated for its silver value.

Conveyor fixture drippings are just one source of reclaimable silver. There are others. For example, suppose you're hand-cutting brazing filler metal strip to make custom-shaped shims for brazing carbide tool tips. The leftover scrap has just as high a silver content as the brazing shim itself.

Depending on the nature of your brazing operations, there's always the possibility that you're generating enough scrap to make accumulation of it over a period of time very worthwhile.

The fact is—the refining of brazing filler metal scrap can often substantially reduce the cost of brazing operations. Your Lucas-Milhaupt representative can help you spot the "hidden treasure" in your operation and implement the best salvage procedures.

Balancing the picture.

We've discussed the six basic steps required in correct brazing procedures. And we've gone into a fair amount of detail in order to be as informative as possible.

To get a more balanced picture of the overall brazing process, it's important to note that in most day-to-day brazing work, these steps are accomplished very rapidly.

Take the cleaning process, for example. Newly-fabricated metal parts may need no cleaning at all. When they do, a quick dip, dozens at a time, in a degreasing solution does the job.

Fluxing is usually no more than a fast dab of a brush or dipping ends of the parts in flux.

Heating can often be accomplished in seconds with an oxy-acetylene torch. And flowing the filler metal is virtually instantaneous, thanks to capillary action.

Finally, flux removal is generally no more than a hot water rinse, and oxide removal needs only a dip into an acid bath.

There are exceptions to the rule, of course, but in most cases a brazed joint is made fast—considerably faster than a linear welded joint. And, as we'll see later on, these economies in time and labor are multiplied many times over in high production automated brazing.

The pure *speed of brazing* represents one of its most significant advantages as a metal joining process.

Section 2: Brazing In Action

Case studies of brazing applications.

In this section, we move from the theoretical to the practical.

On the following pages, we discuss a number of current brazing applications, all of them using Lucas-Milhaupt brazing materials. In each case, we describe and picture the application and explain why brazing was chosen as the preferred joining method.

Even this relatively limited number of examples furnishes a good idea of the immense flexibility of the brazing process.

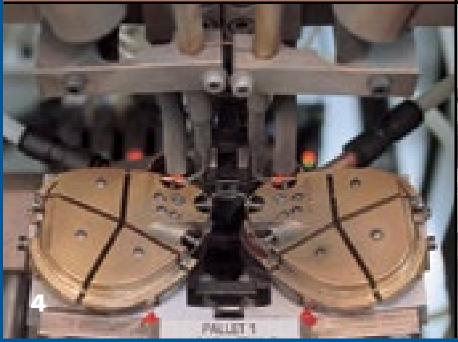
The examples illustrate a wide range of sizes and types in brazed assemblies—from fine wire sunglass frames to industrial air conditioning coils.

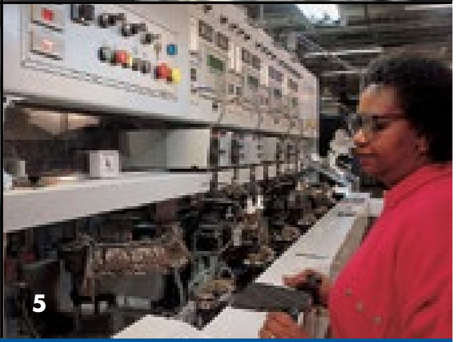
They show how a great variety of dissimilar metals, both ferrous and nonferrous, are joined into single assemblies.

There are examples of different types of heating methods and production techniques ranging from simple torch brazing to fully automatic processes using Lucas-Milhaupt equipment.

And the case studies help illustrate the many forms of filler metal options used in modern brazing including paste, foil, rings and stock and custom preforms.

We hope these examples will help stimulate your thinking about new possibilities for brazing in your own manufacturing operation. They may also suggest procedures, equipment and techniques that will help you braze more efficiently.





1. The bridge of a sunglass frame is brazed.
2. Various metal frame parts are joined during the induction brazing process.
3. Lucas-Milhaupt filler metal in wire form is used.
4. Brazing provides invisible joints as this browbar is brazed.
5. A total of 10 joints are formed during the fully automated process.

Application: Wire frame sunglasses, manufactured by Bausch & Lomb, Co., in Rochester, N.Y.

The brazing story:
Bausch & Lomb uses the brazing process to produce the ten joints needed for the Ray-Ban wire frames available in its sunglasses product line.

The component metal parts of frame fronts, which consist of an eyewire, endpieces, a bridge, a brace and a browbar, are constructed of nickel or a nickel alloy. To form the sunglass front, they are joined together by induction brazing in a series of steps. At each step of the process, they are held in place by a jig. The Lucas-Milhaupt brazing filler metals typically used for the joints are 50% silver-bearing alloys such as SILVALOY® 505. In some instances, Handy Flux or Handy Flux Type B-1 is used to insure optimal wetting action.

When the brazing process is complete, the fronts are pickled to remove any discoloration, polished, and then plated in the desired color. The brazed joints in the finished frames are virtually invisible to the eye.

Why brazing? When people buy sunglasses, appearance is key in their selection process. Brazing's ability to produce invisible joints makes it the only logical choice in metal joining options for the Bausch & Lomb line. Plus, the strength and durability of brazed joints help insure the sunglass frames hold up to the rigors of regular use.

Section 2: Brazing In Action

Brazing Provides Leak-Free Passage For Vehicle Fuel.

Application: Fuel senders used in vehicles manufactured by Ford Motor Company.

The brazing story:

Ford Motor Company relies on brazing in several phases of vehicle manufacture. In the assembly of its fuel pump systems, brazing helps provide a leak free route for gasoline to be transported to the engine. Specifically, brazing is used to construct the fuel sender, a part that mounts directly onto a vehicle's gas tank. With a fuel pump attached to it, the fuel sender pulls gas out of the tank and sends it through tubes to the fuel injection system.

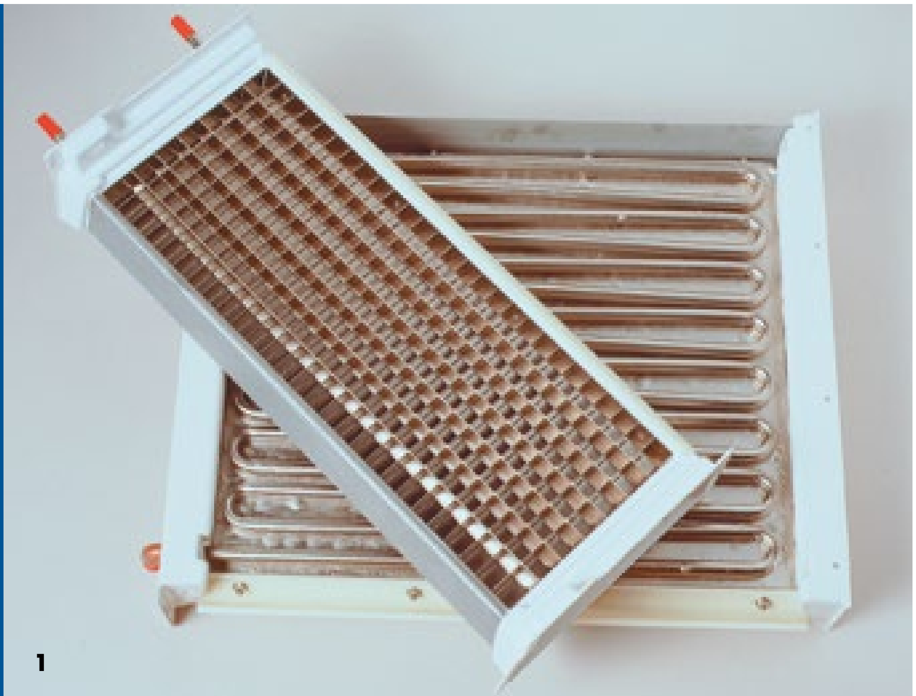
In the manufacture of the fuel sender, two stainless steel arched tubes are brazed through a round stainless flange. The tubes fit neatly between the two existing holes in the flange. An operator manually snaps a C-shaped arc of filler metal, (Lucas-Milhaupt's CDA-521), into the gap between each tube and the flange. The parts are then placed on a belt and sent through an oxygen-free, controlled-atmosphere furnace. The absence of oxygen eliminates the need for flux or cleaning, and the brazed parts emerge shiny and clean.

Following this rapid metal joining process, each fuel sender is 100% leak tested.

Why brazing? At Ford, Quality is Job 1. That's why the automaker relies on brazing to construct its fuel senders. The operation itself is simple and cost-efficient, and the brazed parts are leak-free and attractive to the eye.

1. Teams of Ford employees place the stainless tubes in place in the flange.
2. Filler metal arcs are manually positioned to fill the gap between each tube and the flange hole.
3. Assembled parts are placed on a conveyor for brazing.
4. Finished fuel senders are leak tested.

Automated Soldering Of Ice Tray Assemblies Is A Cool Process.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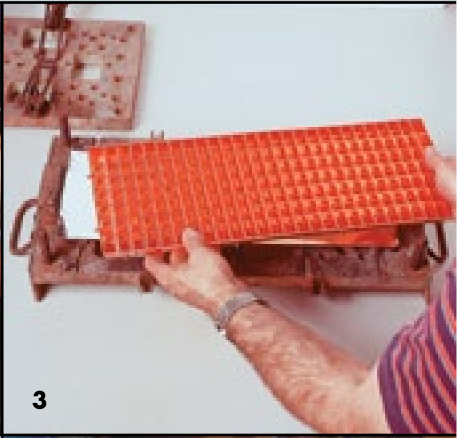
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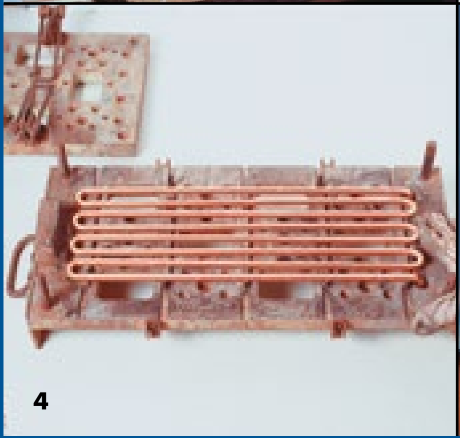
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1. The completed ice cube tray parts.
2. A coating of filler metal paste is applied to the tray.
3. The tray is positioned on the pre-cut and trimmed foil.
4. The coils prior to soldering.
5. An operator positions the ice cube tray parts on a conveyor for soldering.

Application: Ice trays used in large, industrial ice cube machines manufactured by IMI Cornelius of Mason City, Iowa.

The soldering story:
Hotels, motels, restaurants, and other commercial and industrial businesses look to IMI Cornelius to make sure they never run out of ice. IMI Cornelius looks to Lucas-Milhaupt products to ensure the ice cube trays inside their equipment consistently deliver the cold goods.

In the tray assembly process, a metal grid used to form the actual cubes is joined to the inside of the tray, and a serpentine coil that delivers coolant to the grid is joined to the tray back. Soldering is the metal joining method used for both steps which are performed simultaneously.

To join the metal grids to the tray, IMI uses tin silver solder paste filler metal, a step-saving product that includes flux. A tin silver foil is used to join the coil to the tray back. Lucas-Milhaupt provides the foil in sheets cut to match the width of the trays, and IMI trims to the desired length.

An operator-controlled process applies both the paste between the metal grid and the tray, and the foil strips and flux between the tray and the coil. The tray then moves on a conveyor into the furnace for the soldering process.

Why soldering? IMI Cornelius relies on soldering to produce a strong, consistent and cost-effective assembly in its plated ice cube trays. The process used is identical to brazing with the only difference being the use of a lower melt temperature (under 840°F).

Section 2: Brazing In Action

Automated Brazing Of Aluminum Tubing.

Application: Tubing assemblies for air conditioning components produced by ITT Industries, Fluid Handling Systems.

The brazing story:

ITT Industries, a leading supplier to major automakers, manufactures aluminum tubing assemblies for vehicle air conditioning components. The company makes both inlet and outlet tubes for condensers and evaporators and a tube header for air conditioning condensers.

ITT relies on brazing in a variety of different processes throughout its facility; from 2-piece assemblies to the more complex tube headers requiring up to seven brazing operations. Most involve the joining of aluminum components using paste, flux and/or preforms.

All ITT's brazing operations are semi-automated. Aluminum tubing is joined at multi-station index tables. Steps in the process include loading the parts, application of filler metal, heating, cooling and cleaning.

Why brazing? ITT Industries' customers, looking for a high quality, cost effective part, specify that brazing be used in the production of their tubing assemblies. In this application, brazing is the logical choice as it provides a dependable, strong joint at the most economical cost.


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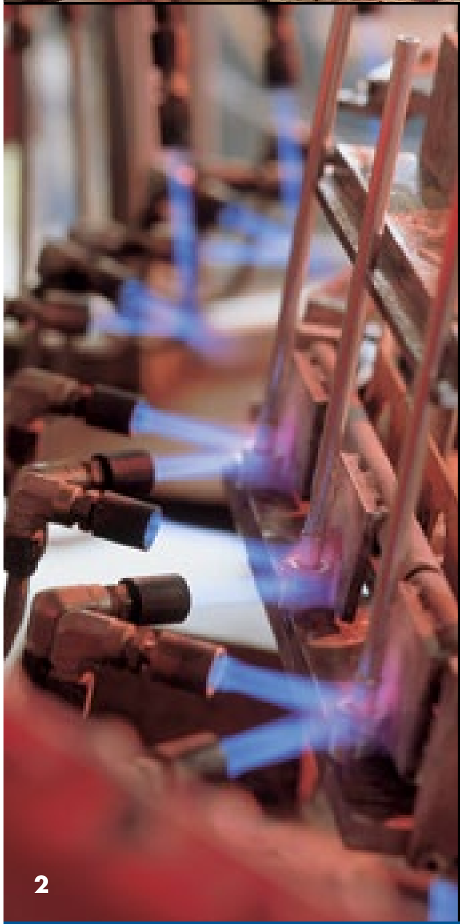
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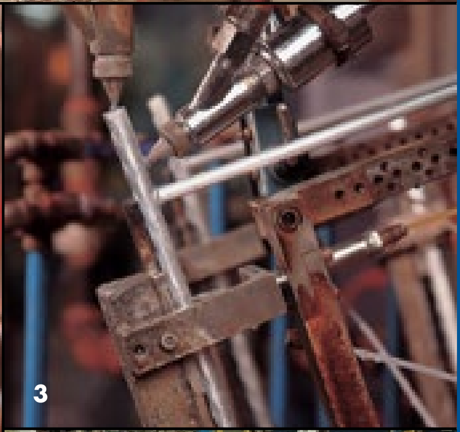
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1. Inlet and outlet tubes are brazed at an automated index table.
2. Brazing in action.
3. Aluminum paste or flux is dispensed in pre-measured amounts.
4. One of several semi-automated systems at ITT.

Section 2: Brazing In Action

Brazed metal chairs stand up to close inspection.


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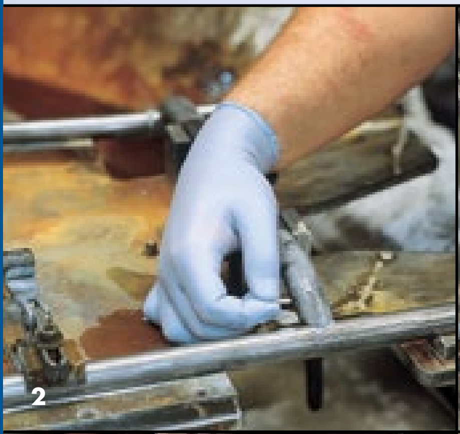
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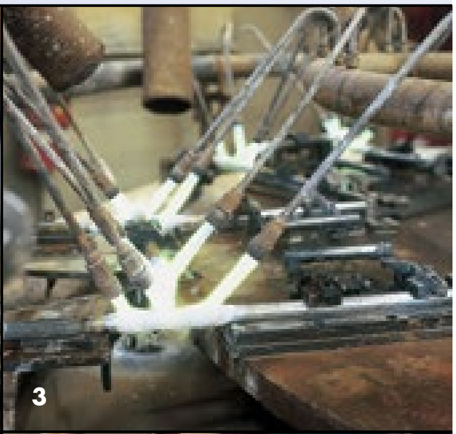
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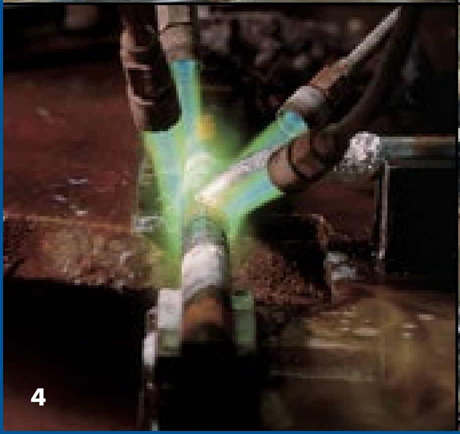
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1. KI relies on brazing to ensure appearance and strength in its Versa chairs.
2. A technician positions the filler metal.
3. Pre-heating of joints.
4. Final heating station, where joints are completed.
5. Water quenching helps to clean the brazed metal frames.

Application: Metal frame chairs and other furniture manufactured by KI (Krueger International), of Green Bay, WI.

The brazing story:

In 1941, KI introduced its initial product, a steel folding chair, and today markets an extensive line of seating, tables and other furnishings. The company relies on brazing and Lucas-Milhaupt filler metals to ensure smooth, strong and invisible joints in the metal frames of its products.

Brazing is used in a variety of products at KI, and is a critical step in the manufacture of the company's high volume, Versa brand chairs. The metal framed product line ranges from individual chairs with poly, wood or fabric seats to tandem seating units and children's furniture.

Although the number of brazed joints per piece may vary, in most cases the joints are formed where the metal seat base and leg pieces come together. In all cases, like metals are joined, usually steel to steel. The brazing process takes place at an index station where multiple frames are joined simultaneously. An operator manually positions a ring or slug (SILVALOY® 505), in position on the frame parts. Flux is applied, and the parts are rapidly heated using gas-air torches. Once brazed, the finished frame is cooled using forced air and then water quenched to clean.

Why brazing? Brazing is the only choice when appearance and strength are critical. By brazing the metal frames on its Versa chairs, KI is ensured of not only strength and durability in its joints, but also a consistently smooth, clean and beautiful joint.

Section 2: Brazing In Action

Brazing Boosts Appearance And Strength Of Pressurized Sprayers.

Application: Pressurized sprayers manufactured by Milwaukee Sprayer Mfg. Co., Inc. in Milwaukee, WI

The brazing story:

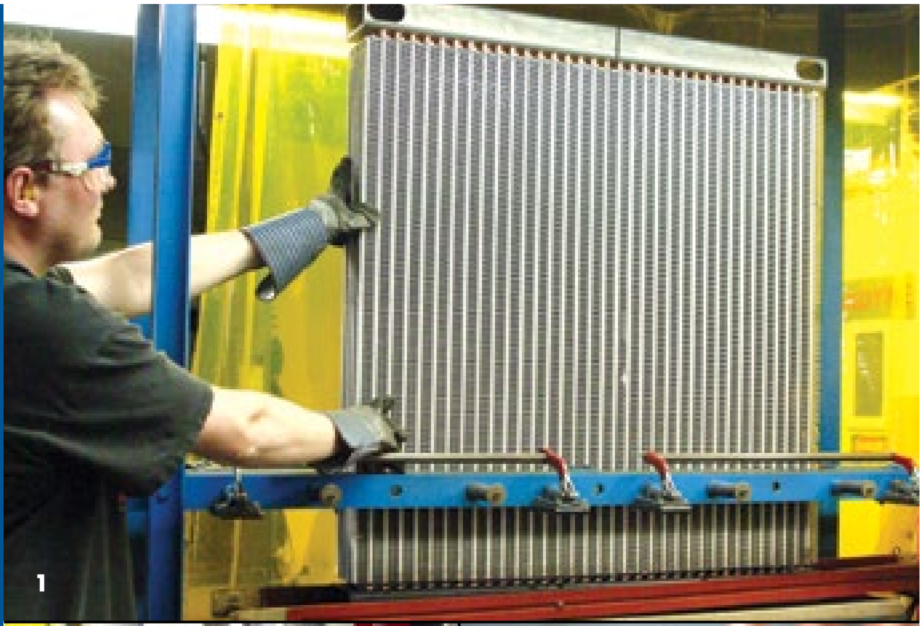
In the manufacture of its pressurized sprayers, Milwaukee Sprayer relies on the brazing process to join brass to brass and form three separate joints. Using a torch to heat, an operator brazes inlet and outlet adapters onto the top of the brass sprayer shell. Two distinct joints are made. The third joint is formed when the bottom portion of the sprayer is joined to the shell. This process is semi-automatic and occurs as the part is rotated in an automated flame brazer.

To produce the strong brazed joints, Milwaukee Sprayer uses Lucas Milhaupt's SILVALOY® 380 and 505 special-purpose alloys, all in ring form. Prior to brazing, the parts are coated with Handy-Flux to prevent oxide formation during heating. Once the joints are formed, the parts are air cooled, quenched in hot water and cleaned. In total, the entire brazing process is completed in about 45 seconds. The finished pressurized sprayer is strong and leak-tight.

Why brazing? Brazing is the optimum choice to produce an attractive pressurized spray can. With all brass to brass connections visible to the eye, brazing's invisible joints help ensure the very best product appearance. Along with this aesthetic benefit, the process guarantees joints that are strong and durable.

1. Brazing produces virtually invisible joints for optimum appearance.
2. Three joints are brazed in the can assembly.
3. An application of flux prevents oxide formation during heating.
4. Using an automated flame brazer, the can bottom is joined to the shell.
5. The finished parts are quenched in hot water and cleaned.

Flux Cored Brazing Rings Improve Efficiency.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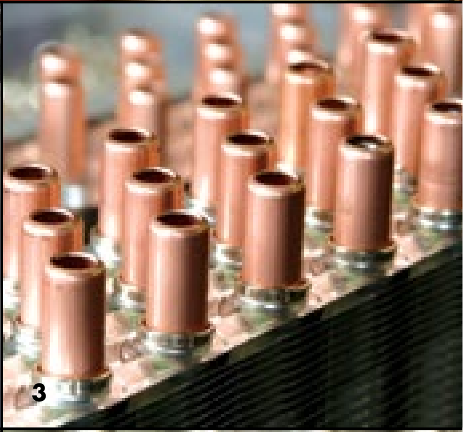
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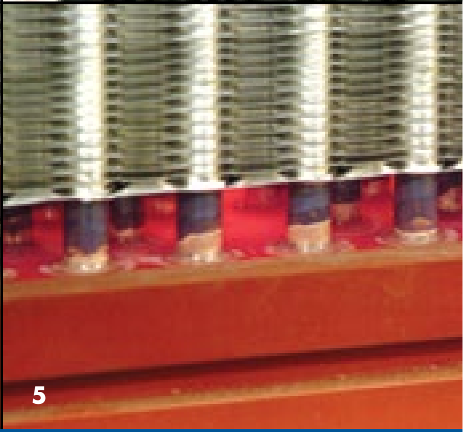
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1. Handy One® flux cored brazing alloys are ideal for products such as heat exchangers because they simplify the brazing process and provide stronger, better quality joints.
2. Flux cored brazing rings are placed onto the copper tubes.
3. Oval rings provide increased surface area and improved alloy flow.
4. The brazing flux mets and flows from the internal seam of the brazing ring, uniformly coating the base metal around the circumference of the joint.
5. The brazing alloy has melted, completing the joints.

Application: Large copper tube aluminum plate fin heat exchangers for heavy-duty cooling applications are manufactured by Thermal Transfer Products, a ThermaSys Company in Racine, WI.

The brazing story:

In the manufacture of their heat exchangers, Thermal Transfer utilizes induction brazing to join copper tubes to a steel manifold. Brazing provides flexibility in the manufacturing process as their units vary in both the size of the tubes, and in the number of rows of tubes that are to be joined.

Preformed rings of Handy One® Flux Cored SILVALOY® 560 (cored with a boron-modified flux) are applied to the copper tubes prior to assembly. No additional flux is required and ascetically superior, leak-free joints are produced when compared to traditional solid wire and flux.

Thermal Transfer has found that their switch to flux cored materials has reduced their leak rate and saved them time and money in their brazing operation. Some advantages they've cited include the elimination of a separate fluxing operation as well as their post braze cleaning. Other benefits include a reduction in the amount of filler metal used because the alloy stays confined to the joint area, and improved post-braze operations (fabrication and welding) due to the reduction of flux residue.

Why brazing? Thermal Transfer requires a high quality, cost efficient process in the production of their industrial heat exchangers. The use of flux-cored rings from Lucas-Milhaupt was an ideal fit for their application.

Section 2: Brazing In Action

Faucet Assembly Taps Into Benefits Of Brazing.

Application: Kitchen and bath faucets manufactured by Wolverine Brass of Conway, S.C.

The brazing story:

A number of different brazing processes are used in the production of the faucets made by Wolverine Brass. One instance is the manufacture of the spout assembly. In this process, three brass components are joined together to form the faucet spout. An aerator adapter and a hub are each joined to a spout tube.

Using a 12 station indexing table with two assemblies per station, the components are joined in an efficient, fully automated process. Lucas-Milhaupt 45% silver brazing alloy in both a paste and wire form joins the brass parts to produce the final assembly. With the three components in place, the aerators are striped with paste and attached to the spout tube. At the same time, an automatic wire feed positions the brazing filler metal wire between the hub and the spout tube. A Handy® Flux Type B1 is applied and, using gas manifold heat, the assembly is brazed.

Following the brazing process, the assembled spouts are air cooled and a series of water tanks are used for cleaning. In total, the entire process requires less than 23 seconds.

Why brazing? Brazing produces strong, leaktight and corrosion resistant joints in a cost-efficient manner. In this type of product, where appearance is critical, the process produces virtually invisible joints.


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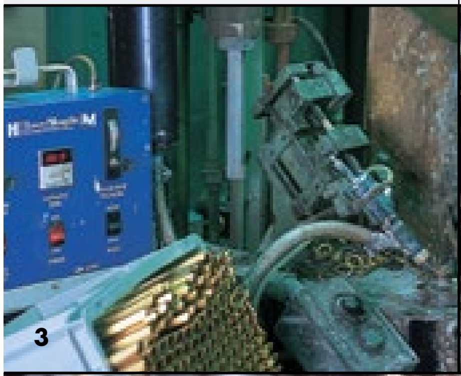
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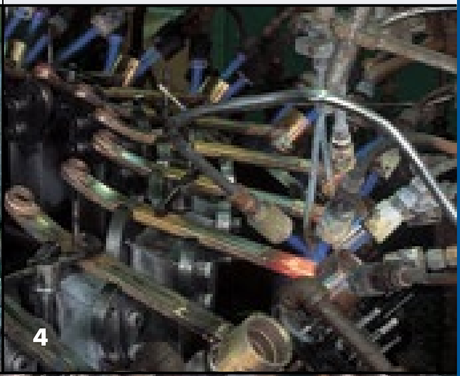
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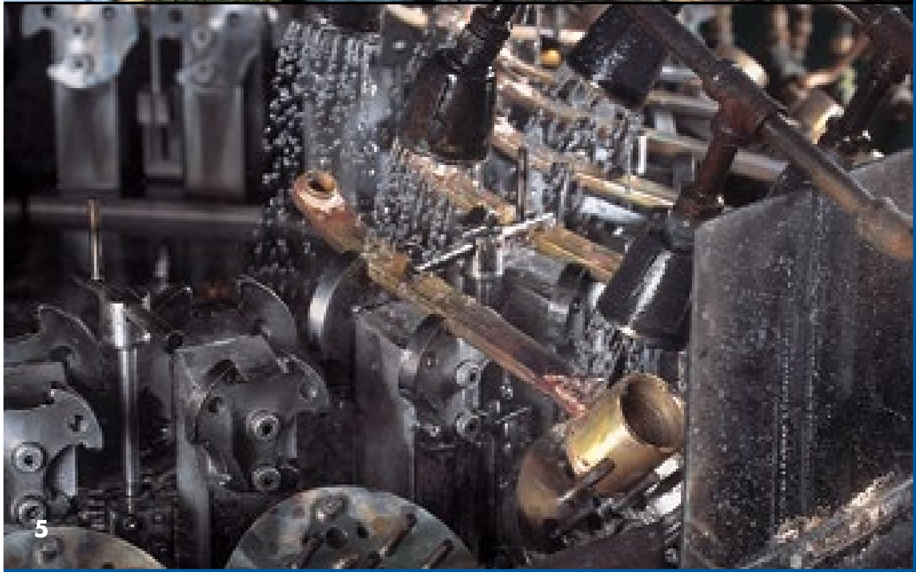
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1. A beautiful finished Wolverine faucet.
2. Three brass components are joined to form the faucet spout.
3. Flux is applied to the aerator in this automated process.
4. The faucet spout is brazed to the body.
5. Following the brazing process, the spouts are cleaned using a series of water tanks.

Products to meet your brazing needs.

Lucas-Milhaupt offers you the widest assortment of filler metals in the industry allowing you to select the most efficient alloy for your assembly and process. Our general purpose filler metal inventory is extensive including Easy-Flo® alloys and cadmium free alternatives.

An assortment of copper-phosphorous filler metals including Sil-Fos® and Fos-Flo® alloys are available.

When specialty alloys are needed, we offer a variety of gold alloys, vacuum grade filler metals, Hi-Temp® alloys, copper filler metals, aluminum alloys and soft solders.

Section 2: Brazing In Action

Off-the-shelf or custom-made, Lucas-Milhaupt can provide you with the most efficient, reliable and cost effective filler metal forms. Options include foil, paste, preforms, rings, strip and wire.

As flux is often critical to the brazing and soldering process, we offer a wide variety of flux products. This includes the Handy Flux® line of general purpose and specialty fluxes which have been the standard in the industry for well over 70 years.


HANDY FLUX
HANDY FLUX
HANDY FLUX
HANDY DRY FLUX
HANDY FLUX TYPE B-1
HANDY FLUX
HANDY LIQUID FLUX
HANDY FLUX


HANDY FLUX BRAZING PASTE
HANDY FLUX SOLDERING PASTE

Section 3: Choices In Brazing Material

Selecting your brazing materials.

Before choosing a filler metal, you must understand and evaluate the three basic characteristics of filler metals: *physical properties*, *melting behavior* and *forms available*. Let's look at each of these characteristics.

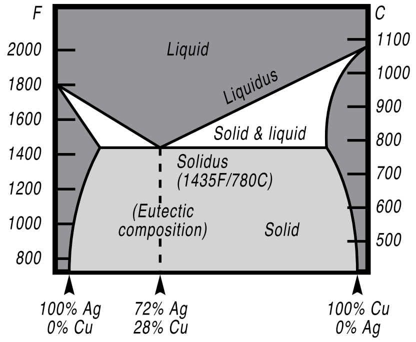
Physical properties and melting behavior.

The *physical properties* of a filler metal are based on metallurgical composition. (Brazing filler metals are invariably alloys, made of two or more "pure" metals.) This composition determines whether the filler metal is compatible with the metals being joined—capable of wetting them and flowing completely through the joint area without forming detrimental metallurgical compounds. Plus, special service or production requirements may call for special properties. For example, if you're brazing in a vacuum, you need a filler metal free of any volatile elements, such as cadmium or zinc. Some electronic components require filler metals of very high purity. And corrosion-resistant joints need filler metals that are both corrosion-resistant and compatible with the base metals being joined.

Melting behavior is also based on metallurgical composition. Since most filler metals are alloys, they usually do not melt the same as pure metals, which change from a solid to a liquid state at one temperature. However, there is an important exception to this statement. There is a class of alloys, termed "eutectics," that *do* melt in the same manner as pure metals. An example of an eutectic composition is SILVALOY® 721, a simple silver-copper alloy made of 72% silver and 28% copper. This filler metal melts completely at a single temperature—1435°F (780°C). In metallurgical terms, its melting point (solidus) and flow point (liquidus) are identical.

This *melting behavior* is shown on the following chart. Note that at the 72% silver, 28% copper composition, liquidus and solidus temperatures are the same. And, the alloys to the left or right of this eutectic composition do not go directly from a solid to a liquid state, but pass through a "mushy" *range* where the alloy is both solid and liquid. This range is the difference between the "solidus" temperature, which is the highest temperature at which the alloy is completely solid (i.e., the point where melting starts when the alloy is heated) and the "liquidus" temperature, which is the lowest temperature at which the alloy is completely liquid (i.e., the point where solidifying starts as the alloy is cooled.)

Silver-copper equilibrium diagram



Importance of "melting range."

Look at a couple of examples. If you are brazing an assembly with a narrow, closely controlled clearance, SILVALOY® 560 filler metal works well. This cadmium free alloy begins to melt at 1145°F/620°C and flows freely at 1205°F/650°C. Its melting range is 60° F/ 15°C. When brazing an assembly with wide clearances (greater than .005"), select a filler metal like the cadmium free Silvaloy 380. As it starts to melt at 1200°F/650°C and becomes fully liquid at 1330°F/720°C, its flow characteristics are sluggish enough to fill wide gaps.

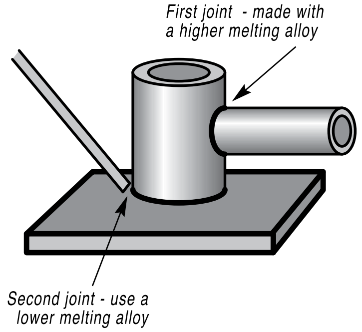
Consider the "liquidus temperature."

In all brazing applications, the *"liquidus temperature"* of the brazing filler metal is a critical factor. Since in brazing you never want—or need—to melt the base metals, you should select a filler metal whose liquidus temperature is *lower* than the solidus temperature of both of the base metals being joined.

There are several brazing situations in which the liquidus temperature factor calls for special consideration.

For example, when "step brazing" an assembly—that is, brazing in the vicinity of a previously brazed joint, you don't want the second brazing operation to disturb the first joint. The way to prevent this is to use more than one type of filler metal. Make the second joint with a filler metal *lower in liquidus temperature* than that used for the first joint. This way you are assured the first joint will not be remelted when making the second.

Also consider liquidus temperature when brazing assemblies that must be heat treated. In these instances, you have two options. You can heat treat and then braze—in which case you should select a filler metal whose liquidus temperature is lower than the heat-treating temperature. This way the hardness properties won't be adversely affected by brazing. Or you can heat treat and braze simultaneously. In this case, the liquidus temperature of the filler metal should be closely equivalent to the heat treating temperatures.



Brazing temperature.

In most cases, the brazing temperature will be above the liquidus temperature of the filler metal and below the solidus temperature of the metal being joined. The actual brazing temperature will depend on factors such as the rate of heating, the type of filler metal flow required, the melt range of the filler metal and any elements in the filler metal that may inhibit flow.

In general, rapid heating and the use of eucectic compositions or alloys with small melt ranges will allow you to braze at a lower temperature. There are a few filler metals which will flow acceptably below their liquidus temperatures. These are the Fos-Flo® and Sil-Fos® filler metals.

Forms of filler metal.

Finally, in selecting a brazing filler metal, consider the *forms* in which it is available; as coils or spools of wire, lengths of rod, strip, powder, paste and preforms (including flux coated products).

In maintenance brazing, single assembly brazing or short-run production, the manual torch, with wire or rod fed by hand, remains the most widely used method. Preforms and pastes are used frequently in production brazing. Evaluate your needs and select the form that provides the best results and most efficient use of material. The information at right should help you in your selection.

How much filler metal to use.

Once you've carefully determined the best filler metal for the job, you need to figure out how much filler metal is needed for the joint.

When brazing a single assembly, this is seldom a problem. You touch the brazing rod to the heated joint area, a portion of the rod melts and capillary action draws it through the joint. When you remove the rod from the joint, you can see the fine line of filler metal running all around the joint edge. No calculation is needed.

When in doubt during maintenance brazing or in short-run production, the rule of thumb is to use *more* rather than *less* filler metal. Joint soundness is your primary goal, so it's best to use a little extra filler metal to insure that soundness.

In high production brazing, however, particularly where you're pre-placing or automatically feeding the filler metal, unnecessary use of filler metal can be costly. Here you want to calculate the amount of filler metal as precisely as possible, so you make sound joints with *minimum* usage of materials. To accomplish this, calculate the volume of the joint (at the brazing temperature), adding 10-25% for fillet and shrinkage, and then supply the equivalent volume of filler metal.

Using the Selection Charts.

One final word on filler metal selection—manufacturers' selection charts can make your job easy. Make use of them and you won't have to be a graduate metallurgical engineer to pick the right filler metal for your brazing application. For example, the chart on pages 34-37 guides you to the right Lucas-Milhaupt filler metal with little difficulty.

Let's look closer at this chart. Note that a relatively few "general purpose" alloys can cover over 90% of your brazing needs. And for specialized applications, you can readily determine the "special purpose" alloy best suited to the job. The chart also includes all the information you need on the melting range and metallurgical composition of each filler metal.

It's important to remember that every brazing and soldering application has requirements which may make one filler metal alloy and form more appropriate and cost effective than another. When you need assistance, let our technical experts evaluate your unique needs and give you a completely objective recommendation.

Selecting a filler metal form.

Filler metals for brazing applications are available in numerous forms.

Powders - Filler metal powders are produced in a range of particle sizes. Although the standard is -100 mesh (-150 microns), other sizes can be produced to meet specialized needs. Prior to brazing, most powders are turned into a paste form, however there are some applications where powder is used directly. The distinct advantage of a powder form is the wide spectrum of available alloys. A variety of alloys can be produced in powder form but because of their unique characteristics cannot be made into wrought form or preform parts.

Paste - Brazing paste is produced by combining one or more parts of a filler metal, flux and a binder component. It comes in a consistency of caulking compound and can be easily dispensed making it ideally suited for manual applications and cost-saving automation. Using dispensing equipment, the desired quantity of paste can be placed directly, in a variety of configurations, on the joint to be brazed. Paste, like powders, offers a much wider choice of alloys. Paste can also be tailored to meet special application needs by varying the ingredients. Finally, since flux may already be formulated into the product, the extra step to apply flux is eliminated.

Wire, Rods and Strips - Coils or spools of wire, lengths of rod and filler metal strips work well in maintenance brazing, one-assembly-at-a-time brazing or short-run production where the wire or rod is fed by hand. These traditional forms of filler metal are available in stock sizes or, upon request, can be modified to custom widths and thicknesses to provide the best use of material. In automated production, rods and strips are typically not the best option.

Preforms - Filler metal preforms are manufactured by forming bulk wire and strip into special shapes. A variety of shapes can be produced, from simple to intricate, to best meet the needs of each application. There are many advantages to preforms. Because preforms permit alloy pre-placement, they are highly adaptable to automation. Automation increases overall production rate and allows the use of unskilled labor; both of which save time and money. Preforms also help minimize and standardize costs. Hand feeding filler metal may use up to 50% more alloy than actually necessary. Preforms are measured amounts of alloy ensuring the exact volume required is used every time. Aesthetically, preforms help improve a part's appearance. Preforms are designed to surround the joint providing a smooth look with only a thin line of alloy visible. Since the correct amount of alloy fills the joint area, this usually results in a reduction of rejected parts.

Flux-Cored Forms - Some filler metal forms are available with a flux-coring. The advantage to these types of forms is that the final fluxing step is eliminated. The final cleaning step is easier as well with less contaminants going out with the rinsing water.

Lucas-Milhaupt Brazing Filler Metals

	Filler Metal Name	Typical Applications
Cadmium-Bearing Filler Metals	EASY-FLO® 45	Joining ferrous, nonferrous and dissimilar metals and alloys with close joint clearances.
	EASY-FLO	Same as EASY-FLO 45.
	EASY-FLO 35	Similar to EASY-FLO 45, but used where joint clearances are large and fillets are desired.
	EASY-FLO 30	Similar to EASY-FLO 35, but used for more economical joints.
	EASY-FLO 25	Same as EASY-FLO 30, but used for most economical joints.
	EASY-FLO 25HC	Same as EASY-FLO 35, but used for more economical joints.
	EASY-FLO 3	For 300 series stainless steels; for joining tungsten carbide, beryllium copper and aluminum bronze to steel.
	EASY-FLO 053	A high temperature solder for medium strength joints above that of soft solders. Use TEC flux.
	EASY-FLO 44	Low melting filler metal for brazing electrical contacts and molybdenum or copper-tungsten electrodes.
Cadmium-Free Filler Metals	SILVALOY® 051	Brazing nichrome resistance elements, or simultaneous brazing and heat treating of steels.
	SILVALOY 071	Used when heat treatment follows brazing, as a lower melting alloy than copper, or in vacuum systems.
	SILVALOY 090	For copper base alloys such as in band instruments; or joint brazing/cyanide case hardening of steels.
	SILVALOY 202	For simultaneous brazing and heat treating of steels.
	SILVALOY 250	Low silver filler metal for joining ferrous and nonferrous alloys.
	SILVALOY 252	Economical filler metal for tungsten carbide, stainless steel and steel.
	SILVALOY 255	Economical filler metal for ferrous and nonferrous joints not requiring high ductility or impact strength.
	SILVALOY 300	For steel and nonferrous alloys melting above 1450°F (790°C), nickel-silver knife handles, electrical equipment.
	SILVALOY 351	Intermediate temperature filler metal for use with ferrous and nonferrous materials.
	SILVALOY 380	Free flowing, cadmium-free filler metal used with ferrous and nonferrous base metals.
	SILVALOY 401	For copper base alloys, mild steel, nickel and Monel, and where a narrow melt range is desired.
	SILVALOY 402	A free-flowing medium temperature filler metal for ferrous and nonferrous alloys.
	SILVALOY 403	For tungsten carbides, and stainless steel food handling equipment allowing no cadmium.
	SILVALOY 404	For tungsten carbides and stainless steel.
	SILVALOY 450	For ships' piping, band instruments, aircraft engine oil coolers, brass lamps.
	SILVALOY 452	Low temperature, free-flowing, Cd-free alloy.
	SILVALOY 495	For low-temperature brazing of tungsten carbides and stainless steels.
	SILVALOY 501	For steam turbine blading and heavily galvanized or tinned steel, aluminum brass tubing.
	SILVALOY 502; 503 (VTG)	For applications similar to SILVALOY 720 and 721 except where better gap filling is needed.
	SILVALOY 505	For 300 series stainless steel food handling equipment with close joint clearances.
	SILVALOY 541	Atmosphere furnace brazing for high temperature applications (up to 700°F/370°C), such as on jet engines.
	SILVALOY 559	Same as SILVALOY 541, but used where zinc fumes in the furnace are not permissible.
	SILVALOY 560	For food handling equipment requiring a low melting, cadmium-free alloy.
	SILVALOY 580	A free flowing filler metal used in brazing tungsten carbide which is subsequently titanium nitrided.
	SILVALOY 600	For Monel and other nickel alloys, and in place of SILVALOY 650 on silverware.
	SILVALOY 603; 604 (VTG)	For vacuum tube seals, brazing of ferrous and nonferrous alloys without flux, for brazing marine heat exchangers exposed to salt water at elevated temperatures (where zinc is objectionable).
	SILVALOY 630	On 400 series stainless steels for corrosion resistance to salt spray, chlorine solutions, etc.
	SILVALOY 650	For silverware, iron and nickel alloys.
	SILVALOY 655	For brazing Invar, Kovar and similar alloys to copper in vacuum tubes; as jet engine rubbing seals.
	SILVALOY 700	For silverware, when subsequent joints are made with SILVALOY 650.
	SILVALOY 715; 716 (VTG)	Filler metal and high conductivity, similar to SILVALOY 720, but suitable for both ferrous and nonferrous alloys.
	SILVALOY 720; 721 (VTG)	For nonferrous electronic components requiring highest electrical and thermal conductivity. The VTG grade has low volatile impurities, good for use in moderate temperature vacuum systems.
	SILVALOY 750	On silverware for step brazing or enameling; for iron or nickel base alloys.

*Recommended heating methods: F = Furnace; H = Inert atmosphere (e.g. H, Ar, He, N) without flux; I = Induction; R = Resistance; T = Torch and Gas-Air Burner; V = Vacuum.

SAFETY NOTE: While Cadmium-Bearing Alloys have been extremely popular and versatile filler metals for decades, there are potential hazards associated with them due to their toxic nature. These alloys should only be used in well ventilated areas. We are prepared to assist you in the proper and safe use of these alloys. For additional information, contact our Technical Services Department.

This table is intended to cover only a few typical applications of the most frequently used brazing filler metals.
For special brazing applications, contact our Technical Services Department.

Heating Methods*	Solidus		Liquidus		Max. Recom. Brazing Temp. °F	Nominal Composition, %				Joint Color as Brazed	Density** Troy oz/cu in	Electrical Characteristics	
	°F	°C	°F	°C		Ag	Cu	Zn	Others			Conduct. % IACS	Resistivity microhm-cm
TFIR	1125	605	1145	620	1350	45	15	16	24 Cd	Light Yellow	4.96	27.6	6.06
TFIR	1160	625	1175	635	1375	50	15.5	16.5	18 Cd	Light Yellow	4.98	23.9	7.00
TFIR	1125	605	1295	700	1400	35	26	21	18 Cd	Light Yellow	4.84	28.6	6.02
TFIR	1125	605	1310	710	1400	30	27	23	20 Cd	Light Yellow	4.79	31	5.5
TFIR	1125	605	1375	745	1400	25	35	26.5	13.5 Cd	Light Yellow	4.71	29.7	5.7
TFIR	1180	640	1320	715	1400	25	30	27.5	17.5 Cd	Light Yellow	4.67	31.9	5.4
TIR	1170	630	1270	690	1400	50	15.5	15.5	16 Cd, 3 Ni	Light Yellow	5.02	18	9.58
TFIR	640	340	740	395	900	5			95 Cd	Gray	4.65	22	7.90
TFIR	1100	595	1220	660	1400	44	27	13	15 Cd, 1P	Light Yellow	4.86	13.8	12.5
TFIR	1545	840	1615	880	1700	5	58	37		Brass Yellow	4.47	24.4	7.06
TFIHR	1225	665	1805	985	2000	7	85		8 Sn	Yellow	4.80	12.8	13.50
TFIR	1410	765	1565	850	1665	9	53	38		Brass Yellow	4.49	20.5	8.43
TFIR	1315	710	1500	815	1650	20	45	35		Brass Yellow	4.58	23.5	7.36
TFIR	1250	675	1575	855	1665	25	52.5	22.5		Brass Yellow	4.71	24.4	7.06
TFIR	1305	705	1475	800	1650	25	38	33	2 Mn, 2 Ni	Brass Yellow	4.52	10.2	17.2
TFIR	1270	690	1435	780	1600	25	40	33	2 Sn	Light Yellow	4.62	19.4	9.0
TFIR	1250	675	1410	765	1600	30	38	32		Light Yellow	4.66	24.4	6.85
TFIR	1265	685	1390	755	1600	35	32	33		Yellow	4.67	19.8	8.2
TFIR	1200	650	1330	720	1500	38	32	28	2 Sn	Pale Yellow	4.77	18	9.5
TFIR	1245	675	1340	725	1550	40	30	30		Yellow	4.74	20.8	8.3
TFIR	1200	650	1310	710	1500	40	30	28	2 Sn	Pale Yellow	4.76	18	9.6
TFIR	1220	660	1435	780	1600	40	30	28	2 Ni	Light Yellow	4.76	16.8	10.27
TFIR	1220	660	1580	860	1665	40	30	25	5 Ni	White	4.81	13.5	12.80
TFIR	1225	665	1370	745	1550	45	30	25		Yellow White	4.80	19	9.08
TFIR	1195	646	1251	677	1500	45	27	25	3 Sn	Pale Yellow	4.85	18.0	9.6
TFIR	1260	680	1290	700	1450	49	16	23	7.5 Mn, 4.5 Ni	Yellow White	4.70	5.7	30.27
TFIR	1250	675	1425	775	1600	50	34	16		Yellow White	4.92	25.5	6.76
TFIHVR	1435	780	1600	870	1800	50	50			Yellow White	5.08	78	2.2
TFIR	1220	660	1305	705	1500	50	20	28	2 Ni	Yellow White	4.83	49.3	11.95
TFIR	1340	725	1575	855	1700	54	40	5	1 Ni	White	5.07	49.8	3.46
HVR	1420	770	1640	895	1800	56	42		2 Ni	White	5.14	51.2	3.37
TFIR	1145	620	1205	650	1400	56	22	17	5 Sn	White	4.96	8.3	20.75
TFIHV	1120	605	1345	730	1550	57.5	32.5		7.0 Sn, 3.0 Mn	White	5.17	25.3	6.81
TFIR	1245	675	1325	720	1500	60	25	15		White	5.01	21	8.40
TFIHVR	1115	600	1325	720	1500	60	30		10 Sn	White	5.17	7.1	24.10
TFIHVR	1275	690	1475	800	1700	63	28.5		6 Sn, 2.5 Ni	White	5.19	12.8	13.40
TFIR	1240	670	1325	720	1500	65	20	15		White	5.06	21.3	8.10
TFIVRH	1385	750	1560	850	1700	65	28		5 Mn, 2 Ni	White	5.20	12.8	13.40
TFIR	1275	690	1360	740	1550	70	20	10		White	5.15	26.7	6.45
TFIHVR	1435	780	1465	795	1700	71.5	28		.5 Ni	White	5.27	78.8	2.19
TFIHVR	1435	780	1435	780	1700	72	28			White	5.25	87	2.0
TFIR	1365	740	1450	790	1600	75	22	3		White	5.24	53.4	3.23

**Specific Gravity = $\frac{\text{Density (Troy oz/in}^3\text{)}}{.527}$

(This table continued on the following page.)

Fahrenheit to Celsius conversion formula F° to C° = .555 (F° - 32)

Lucas-Milhaupt Brazing Filler Metals

	Filler Metal Name	Typicals Applications
Cadmium-Free Filler Metals (cont'd)	SILVALOY® 852	Brazing stainless, Stellite, Inconel, complex carbides ~~-~~for high-temperature service.
	SILVALOY 999	A VTG alloy for brazing ceramics to be used as semiconductors.
	LITHOBRAZE® 720	For ferrous and nonferrous base alloys; especially thin sections of stainless steels.
	LITHOBRAZE 925	To join skins to honeycomb cores, particularly precipitation-hardening stainless steels.
	PREMABRAZE® 616 (VTG)	For ferrous and nonferrous alloys used in moderate temperature vacuum tubes and systems.
	PREMABRAZE 130	For stainless steel, Inconel X, A286, Kovar, etc., for oxidation and scaling resistance up to 1500°F (815°C).
Hi-Temp Alloys	HI-TEMP® 080	Economical high strength filler metal for joining carbides to alloy steels.
	HI-TEMP 095	High strength filler metal for joining carbides, steels and heat resistant alloys.
	HI-TEMP 548	Tough, moderate strength, low melting improved nickel silver filler metal for carbides, tool steels, stainless stainless steels and nickel alloys.
	HI-TEMP 870	A free flowing, high melting filler metal with good high temperature strength, for brazing carbides, tool steels, stainless steels and nickel alloys.
Silver-Copper-Phosphorus Alloys (See note below)	SIL-FOS® 18	A ternary eutectic filler metal for joints where good fit-up can be maintained and low melting point is of prime importance. Clearance: .001″ to .003″ (.025 mm to .076 mm). Very fast flow.
	SIL-FOS 15	For use where close fit-ups cannot be maintained and joint ductility is important. Recommended joint clearance: .002″ to .005″ (.051 mm to .127 mm). Slow flow. The only phos/copper silver filler metal available in strip or sheet form.
	SIL-FOS 6	A very fluid filler metal for close fit-up work. Low melting range makes it ideal where temperature is a factor.Recommended joint clearance: .001″ to .003″ (.025 mm to .076 mm). Fast flow. Lowest melt and flow in the minimum silver class.
	HANDY FLO® 6 (Formerly Sil-Fos 6M)	Recommended for use where close fit-up cannot be maintained. Has the ability to fill gaps and form fillets without affecting joint strength. Recommended joint clearance: .002″ to .005″ (.051 mm to .127 mm). Slow flow.
	SIL-FOS 5	Designed primarily for those applications where close fit-ups cannot be maintained. It has ability to fill gaps and form fillets
	SIL-FOS 2	A filler metal with comparable characteristics to Fos-Flo. Recommended joint clearance: .001″ to .005″ (.025 mm to .127 mm). Medium flo
	SIL-FOS 2M	Has ability to fill moderate gaps in poorly fitted joints. More ductile than Fos-Flo or Sil-Fos 2. Intended for use on copper tube headers and similar applications where a sleeve fit is not practical. Recommended joint clearance: .002″ to .005″ (.051 mm to .127 mm). Slow flow.
Copper-Phosphorus Alloys (See note below)	FOS-FLO®	An economical, very fluid medium temperature filler metal for use with copper, brass and bronze. Withstands moderate vibration. Recommended joint clearance: .001″ to .003″ (.025 mm to .076 mm). Fast flow.
	FOS-FLO 6	An economical filler metal with a wide melting range and moderate flow. For use where close fit-ups cannot be maintained and ductability is important. Recommended joint clearance is .003″ to .005″ (.076 mm to .127 mm).

*Recommended heating methods: F = Furnace; H = Inert atmosphere (e.g. H. Ar, He, N) without flux; I = Induction; R = Resistance; T = Torch and Gas-Air Burner; V = Vacuum.

**Specific Gravity = $\frac{\text{Density (Troy oz/in}^3\text{)}}{.527}$

NOTE: The SIL-FOS and FOS-FLO filler metals are for use with copper and copper alloy base metals. Do not use these materials to join ferrous materials as brittle phosphide compounds will be formed at the interface. The SIL-FOS and FOS-FLO filler metals have a unique characteristic called the "Flow Point" (listed in parentheses). The ''Flow Point'' is defined as the temperature at which the filler metal is fluid enough to capillary through a joint even though not completely liquid (i.e. above the liquidus temperature).

This table is intended to cover only a few typical applications of the most frequently used brazing filler metals. For special brazing problems, contact our Technical Services Department.

Heating Methods*	Solidus		Liquidus		Max. Recom. Brazing Temp. °F	Nominal Composition, %					Joint Color as Brazed	Density** Troy oz/ cu in	Electrical Characteristics	
	°F	°C	°F	°C		Ag	Cu	Ni	Zn	Others			Conduct. % IACS	Resistivity microhm-cm
FIHV	1760	960	1780	970	2000	85				15 Mn	White	4.98	4.6	37.50
TFIHV	1761	960	1761	960	1900	99.9					White	5.53	105.2	1.59
H	1400	760	1400	760	1600	71.7	28			0.3 Li	White	5.09	50.8	3.39
H	1400	760	1635	890	1800	92.5	7.3			0.2 Li	White	5.33	55.2	3.12
HV	1155	625	1305	705	1500	61.5	24			14.5 In	White	5.19	16	10.70
TIHV	1742	950	1742	950	1950			18		82 Au	Gray	8.33	5.85	29.30
												lb/cu in		
TFI	1575	855	1675	915	1875		54.85	8	25	12 Mn .15 Si	Light Yellow	.290	6.0	28.6
FIHV	1615	880	1700	925	2000		52.5	9.5		38 Mn	Red-Gray	.277	14.7	11.7
TFI	1615	880	1685	920	1900		55	6	35	4 Mn	Light Yellow	.302	10.6	16.2
FIHV	1760	960	1885	1030	2000		87			10 Mn,	Gray	.316	14.5	11.9
TFIR	1190	645	1190	645	1300	18	75.5			6.5 P	Gray	.293	5.9	29.4
TFIR	1190	645	1475 (1300)	800 (705)	1500	15	80			5 P	Gray	.305	9.9	17.4
TFIR	1190	645	1325 (1275)	720 (690)	1450	6	86.75			7.25 P	Gray	.284	7.9	21.9
TFIR	1190	645	1460 (1300)	795 (705)	1500	6	88			6 P	Gray	.292	8.8	19.7
TFIR	1190	645	1495 (1325)	815 (720)	1500	5	89			6 P	Gray	.294	9.6	18.1
TFIR	1190	645	1450 (1325)	785 (720)	1500	2	91			7 P	Gray	.289	5.5	31.5
TFIR	1190	645	1495 (1350)	815 (730)	1550	2	91.4			6.6 P	Gray	.292	7.5	22.9
TFIR	1310	710	1460	795	1550		92.75			7.25 P	Gray	.289	7.5	23.2
TFIR	1310	710	1570	854	1600		93.85			6.15 P	Gray	.293	7.2	24.1

Lucas-Milhaupt Brazing Filler Metals Based on Standard Specifications

AWS A5.8 Class:	ASME Blr. & Pr. Vsl. Cd. Sec. II-C SFA5.8 (1992 Ed.) Class:	Fed Spec. QQ-B-650C (7/23/87) Class:	Fed Spec. QQ-B-654A* Amend. 1 (2/10/84) Grade: (Old Grade)	Society of Automotive Engineers AMS	Lucas-Milhaupt Brazing Filler Metals Corresponding to Standard Specifications
—	—	—	—	4762	SILVALOY® 401
BCuP-2	BCuP-2	BCuP-2	—	—	FOS-FLO®
BCuP-3	BCuP-3	BCuP-3	—	—	SIL-FOS® 5
BCuP-4	BCuP-4	BCuP-4	—	—	SIL-FOS 6
BCuP-5	BCuP-5	BCuP-5	BCuP-5 (III)	—	SIL-FOS 15
BCuP-6	BCuP-6	—	—	—	SIL-FOS 2
BAg-1	BAg-1	—	VII	4769	EASY-FLO® 45
BAg-1a	BAg-1a	—	IV	4770	EASY-FLO
BAg-2	BAg-2	—	VIII	4768	EASY-FLO 35
BAg-2a	BAg-2a	—	—	—	EASY-FLO 30
BAg-3	BAg-3	—	V	4771	EASY-FLO 3
BAg-4	BAg-4	—	BAg-4	—	SILVALOY 403
BAg-5	BAg-5	—	BAg-5 (I)		SILVALOY 450
BAg-6	BAg-6	—	—	—	SILVALOY 501
BVAg-6b	BVAg-6b	—	—	—	SILVALOY 503
BAg-7	BAg-7	—	BAg-7	4763	SILVALOY 560
BAg-8, BVAg-8	BAg-8, BVAg-8	—	—	—	SILVALOY 720 and 721
BAg-8a	BAg-8a	—	BAg-8a	—	LITHOBRAZE 720
BVAg-8b	BVAg-8b	—	—	—	SILVALOY 716
BAg-9	BAg-9	—	BAg-9 (II)	—	SILVALOY 650
BAg-10	BAg-10	—	BAg-10	—	SILVALOY 700
BAg-13	BAg-13	—	—	4772	SILVALOY 541
BAg-13a	BAg-13a	—	BAg-13a	4765	SILVALOY 559
BAg-18; BVAg-18	BAg-18; BVAg-18	—	BAg-18	4773	SILVALOY 603 and 604
BAg-19	BAg-19	—	—	4767	LITHOBRAZE™ 925
BAg-20	BAg-20	—	BAg-20	—	SILVALOY 300
BAg-21	BAg-21	—	—	4774	SILVALOY 630
BAg-22	BAg-22	—	BAg-22	—	SILVALOY 495
BAg-23	BAg-23	—	BAg-23	4766	SILVALOY 852
BAg-24	BAg-24	—	—	4788	SILVALOY 505
BAg-26	BAg-26	—	—	—	SILVALOY 252
BAg-27	BAg-27	—	—	—	EASY-FLO 25
BAg-28	BAg-28	—	—	—	SILVALOY 402
BVAg-29	BVAg-29	—	—	—	PREMABRAZE® 616
BAg-33	BAg-33	—	—	—	EASY-FLO 25 HC
BAg-34	BAg-34	—	—	4761	SILVALOY 380
BAg-35	BAg-35	—	—	—	SILVALOY 351
BAg-36	BAg-36	—	—	—	SILVALOY 452
BAg-37	BAg-37	—	—	—	SILVALOY 255
BVAu-4	BVAu-4	—	—	4787	PREMABRAZE® 131
—	—	—	—	4764	HI-TEMP 095
BAlSi-3	BAlSi-3	—	—	4184	AL 716
BAlSi-4	BAlSi-4	—	—	4185	AL718**

* Federal Specification QQ-B-654A supersedes QQ-B-654, MIL-B-15395A, MIL-S-15395, and QQ-S-561d, and should be used whenever possible instead of the superseded specifications.

** Conforms to chemical composition limits of class 8 of MIL-B-20148C and class FS-BAlSi-4 of QQ-B-655c. Available as a premixed flux-filler metal powder product—Alumibraze and Alumibraze 400—for dip brazing in conformance to Process Specs AMS 2672, AMS 2673, MIL-B-23362 and MIL-STD-645.

Lucas-Milhaupt brazing alloys in powder form.

The atomization process is conducted in an inert gas atmosphere. As a result, the brazing alloy powders are exceptionally clean and free of oxides and impurities.

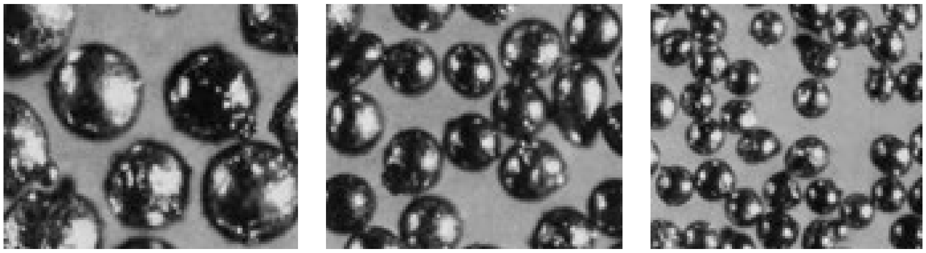
Most Lucas-Milhaupt brazing alloys can be supplied in atomized forms. Control of particle size is extremely close. The powders are supplied in all standard mesh sizes, and may also be furnished, with the same close controls, to size limitations specified by the customer. Filed powders, produced in coarse-sized particles, are also available.

A range of atomization options enables us to meet wide variations in customer requirements—rapidly and economically, providing you the highest quality brazing alloy powders.

Particle Size Comparison Chart

Measurements				Sieve (Screen)	
Millimeters	**Microns (µ)**	**Inches**	**Mils**	**U.S. Std. Sieve Designation***	**Tyler Std. Sieve**
0.0254	25.4	0.00100	1.00	–	–
0.0318	31.8	0.00125	1.25	–	–
0.0381	38.1	0.00150	1.50	38 µm (No.400)	400 mesh
0.0445	44.5	0.00175	1.75	45 µm (No.325)	325 mesh
0.0508	50.8	0.00200	2.00	–	–
0.0533	53.3	0.00210	2.10	53 µm (No.270)	270 mesh
0.0635	63.5	0.00250	2.50	63 µm (No.230)	250 mesh
0.0737	73.7	0.00290	2.90	75 µm (No.200)	200 mesh
0.0762	76.2	0.00300	3.00	–	–
0.0889	88.9	0.00350	3.50	90 µm (No.170)	170 mesh
0.1016	101.6	0.00400	4.00	–	–
0.1050	105.0	0.00413	4.13	106 µm (No.140)	150 mesh
0.1250	125.0	0.00492	4.92	125 µm (No.120)	115 mesh
0.1490	149.0	0.00587	5.87	150 µm (No.100)	100 mesh
0.1770	177.0	0.00697	6.97	180 µm (No.80)	80 mesh
0.2500	250.0	0.00984	9.84	250 µm (No.60)	60 mesh
0.4200	420.0	0.01654	16.54	425 µm (No.40)	35 mesh
0.8410	841.0	0.03311	33.11	850 µm (No.20)	20 mesh
1.0000	1000.0	0.03937	39.37	1mm (No.18)	16 mesh

*In accordance with ASTM E11
''Wire-Cloth Sieves for Testing Purposes''



Shown above are photographs of Lucas-Milhaupt's SIL-FOS 5 powder, in three standard mesh sizes. Photographs are all enlarged 100 times. Note consistency of particle size and shape in all three sizes.

Brazing Ceramic Materials

Normally, the brazing of ceramics is a difficult matter since standard brazing alloys will not wet ceramic materials directly. Two brazing options exist for joining ceramics to metals or ceramic to ceramic.

One method involves coating the ceramic with molybdenum/manganese or some other type of metallizing procedure. Once this is done, the coated ceramic can be brazed with standard filler metal. Unfortunately this metallizing process is very complicated and expensive to perform.

The second option involves a direct brazing process using an active metal. This process is suitably called "active metal brazing."

In active metal brazing, the filler metal used contains active metal additions that wet certain ceramic materials. With this process, ceramics can be directly brazed.

Active metal products will join many types of ceramics and other hard to wet materials like carbide, diamond, sapphire, alumina, zirconia, silicon nitride, silicon carbide, titanium nitride, titanium and beryllium. These materials may be joined to themselves or to common substances such as stainless steel, copper, tool steel, kovar, etc.

In the direct brazing process, the brazing should be done in a vacuum, 1 x 10^{-4} Torr minimum, or in an inert gas atmosphere using argon or helium.

Active metal products are available from Lucas-Milhaupt in two forms; paste and strip.

Paste form can be dispensed or silk screened on the parts to be brazed. This offers the advantage of conformance to any configuration. Wrought form products must be processed to the correct size.

A flux for every brazing need.

Flux is critical to the brazing and soldering process because it minimizes the oxidation that may form on both the brazing filler metal and the materials being joined. Numerous formulations of flux are available for virtually all metal joining operations.

The majority of common brazing applications are readily met by Handy Flux™, the general purpose flux that has remained an industry standard for over 70 years. It is a powerful general purpose flux that protects your parts up to 1600°F (871°C).

For low temperature brazing, Ultra Flux® is a creamy and smooth composition that provides excellent adhesion to parts. Its consistent blend will not spatter or run during a rapid heating cycle. Ultra Flux® offers excellent fluxing action and oxide removal and will not crystallize under normal conditions.

We also offer fluxes for virtually every specialized application including formulations for high and low temperature applications, furnace and induction brazing, as well as those for automatic flux dispensers.

For more information on any of these fluxes, or a recommendation on which flux to use, contact our Technical Services Department.

Brazing and Soldering Fluxes*

Name of flux and Form	Application	Description	Availability
Handy Flux™ *Paste*	All purpose, low temperature flux for use in brazing both ferrous and nonferrous metals and alloys.	Handy Flux is an active flouride/borate-type flux which begins to melt and dissolve oxides at 600°F (320°C). Fully molten at 1100°F (600°C), it provides excellent protection of parts up to 1600°F (870°C). Cleanup should be with hot water.	½, 1 and 5 lb. (227, 454 g. and 2.27 kg.) jars. Also 25 and 50 lb. (11.34 and 22.68 kg.) pails.
Ultra Flux® *Paste*	General purpose, low temperature brazing flux which provides excellent adhesion and creamy smooth consistency. For brazing ferrous and non-ferrous alloys.	Same as Handy Flux. Ultra Flux dissolves the oxides that form on copper brass, nickel, monel, steel and stainless steel during heating. Will not crystallize.	1 and 5 lb. (454 g. and 2.27 kg.). Also 25 and 50 lb. (11.34 and 22.68 kg.) pails.
Handy Flux Type D & DB *Slurry*	For automatic dispensing as controlled dabs or sprays.	This flux has the same combination of salts as Handy Flux, with additives to provide a lower (pourable) viscosity. Type DB has an additional boron formulation for use with more refractory oxides, such as in automated brazing of carbides.	50 lb. (22.68 kg.) pails and 12.5 lb. (5.67 kg.) bottles.
Handy Flux Type B-1 *Paste*	For brazing high chromium stainless steels, tungsten and chromium carbides, and molybdenum alloys.	Particularly in applications where a larger amount of refractory oxides may form, use Handy Flux Type B-1 (boron modified). Its temperature range is 1100° to 1700°F (600°-925°C). It is valuable where local overheating may occur, as in fast induction heating.	1 and 5 lb. (454 g. and 2.27 kg.) jars. Also 25 and 50 lb. (11.34 and 22.68 kg.) pails.
Ultra Black Flux *Paste*	Same as Handy Flux B-1. Ideally suited for induction heating where localized over-heating, or longer heating cycles may occur.	Same as Handy Flux B. Ideally suited where refractory oxides may form (chromium tungsten, etc.). Better brushability and excellent adhesion –will not spatter.	1 and 5 lb. (454 g. and 2.27 kg.). Also 25 and 50 lb. (11.34 and 22.68 kg.) pails.
Handy Flux Type A-1 *Paste*	For brazing aluminum bronze and other alloys containing small amounts of aluminum and/or titanium.	Type A-1 will readily flux the difficult, refractory oxides that form on these alloys–and permits brazing them both to ferrous and nonferrous alloys. It is *not* recommended for use with aluminum- or titanium-*base* alloys. Active range: 1100° to 1600°F (600°-870°C).	1 lb. (454 g.) jars.
Handy Flux Type LT *Paste*	For applications with long heating cycles, such as many furnace brazing jobs.	More effective than a general purpose flux in long-heating-cycle applications. Lower fluorine content results in higher melting temperature. More viscous, less active, but has longer life. Also useful for induction heating applications, where tendency to overheat may exist. Active range: 1200° to 1600°F (650°-870°C).	1 lb. (454 g.) jars.

*For information on proper fluxing procedures, see Page 15.

Brazing and Soldering Fluxes* (cont'd)

Name of flux and Form	Application	Description	Availability
Handy Flux Hi-Temp *Paste*	Used where brazing temperatures go into the 1600° to 2000°F (870°-1100°C) range or for considerable lengths of time above 1450°F.	This high temperature flux contains still less flourine than Type LT. It is often used with brazing alloys melting above 1600°F (870°C)– and provides the adherence and fluxing action a general purpose flux cannot give at these temperatures.	1 lb. (454 g.) jars. Also 25 and 50 lb. (11.34 and 22.68 kg.) pails
Handy Flux Hi-Temp Boron Modified *Paste*	For high temperature Ag, Cu, Ni brazing in the range of 1600° to 2200°F (870°-1200°C), involving longer time or base metals with refractory oxides.	Particularly useful where refractory oxides are formed on the metals being joined. This added capability results from addition of a small amount of finely powdered boron to the flux.	1 lb. (454 g.) jars.
Handy Flux B-1 Dry *Powder*	Recommended with braze filler metals that flow between 1100° to 1700°F (593° – 927°C)	Handy Flux B-1 Dry is an active fluoride/borate-type flux in powder form, which has been specially formulated to provide excellent protection of parts up to 1700°F (927°C).	½ lb., 1 lb. (454 g.), 5 lb. jars, Also 25 lb. (11.34kg.) and 50 lb. pails
Handy Flux Type TEC *Liquid*	For metal joining at temperatures in the 500° to 800°F (260°-425°C) range.	This widely used liquid flux provides excellent performance in soldering applications.	1 pt., 1 qt. and 1 gal. (0.475, 0.95 and 3.79 liter) containers
Handy Liquid Flux *Liquid*	For brazing in furnaces with poor atmospheres or joining jewelry parts above 1160°F (625°C).	Used where only a limited fluxing ability is desired.	1 pt., 1 qt. and 1 gal. (0.475, 0.95 and 3.79 liter) containers

*For information on proper fluxing procedures, see Page 15.

Lucas-Milhaupt Brazing Fluxes Based on Standard Specifications

Source and Number of Specification			
AWS Brazing Flux Classification	**Fed. Spec. O-F-499d (2/6/85)**	**Society of Automotive Engineers AMS**	**Lucas-Milhaupt Brazing Flux Corresponding to Standard Specifications**
FB3A	Type B	3410	Ultra Flux®
FB3A		3410	Handy Flux
FB3C†		3411	Ultra Black Flux
FB3C†		3411	Handy Flux Type B-1
FB3D†		3417	Handy Flux Hi-Temp Handy Flux Hi-Temp Boron Modified
FB3E			Handy Liquid Flux
FB3F			Handy Flux B-1 Dry
FB3G			Handy Flux Type D
FB3H			Handy Flux Type DB
FB4A			Handy Flux Type A-1

†AWS FB3C and FB3D were formerly Type 3B

Copper & Copper Alloys: Brazing Materials Selection Chart

General Group	Principal Types	Nominal Composition—Percentages	Principal Uses	Recommended Brazing Filler Metals*
Coppers	Electrolytic Tough Pitch Phosphorus Deoxidized Oxygen Free, High Conductivity	Cu–99.90 min., O_2–.04 Cu–99.90 min., P–.02 Cu–99.92 min.	Electrical conductors, auto radiators, plumbing, dairy and heat exchanger tubing, busbars and wave guides.	*Cadmium Free Alloys* SIL-FOS & FOS-FLO Series SILVALOY 560, 380, 452 and 402 *Cadmium Alloys* EASY-FLO & EASY-FLO 45 and 35
Red Brasses	Gilding Metal, Commercial Bronze, Jewelry Bronze, Red Brass	Zn–5 to 15, Cu–Balance	Jewelry, marine hardware, heat exchangers, grille work, fire extinguisher cases	*Cadmium Free Alloys* SIL-FOS & FOS-FLO Series SILVALOY 300, 380 and 452 *Cadmium Alloys* EASY-FLO & EASY-FLO 45 and 35
Yellow Brasses	Low Brass, Cartridge Brass, Yellow Brass, Muntz Metal	Zn–20 to 40, Cu–Balance	Musical instruments, lamp fixtures, hinges, locks, plumbing accessories, flexible hose, radiator cores, bellows	*Cadmium Free Alloys* SIL-FOS & FOS-FLO Alloys SILVALOY 202, 300, 380 and 452 *Cadmium Alloys* EASY-FLO & EASY-FLO 45 and 35
Leaded Brasses	Leaded Commercial Bronze, Low Leaded Brass, Medium Leaded Brass, High Leaded Brass, Free Cutting Brass, Free Cutting Muntz Metal, Architectural Bronze	Zn–9.25 to 40, Pb–0.5 to 3 Cu–Balance	Screw machine parts, pump cylinders and liners, plumbing accessories, gears, wheels, pinions, forgings, extrusions	*Cadmium Free Alloys* SILVALOY 560, 603 and 380 SIL-FOS Series *Cadmium Alloys* EASY-FLO & EASY-FLO 45 and 35; SILVALOY 560
Tin Brasses	Admiralty, Naval Brass Manganese Bronze	Zn–28 to 39, Sn–0.75 to 1, Admiralty: As–.04 Fe–1.4, Mn–0.1 All: Cu–Balance	Condenser and heat exchanger tubes and plates, marine hardware, pump rods, shafts and valve stems	*Cadmium Free Alloys* SILVALOY 600, 202, 300, 380, 450 and 560 *Cadmium Alloys* EASY-FLO & EASY-FLO 45 and 35, 560 SIL-FOS Series
Phosphor Bronzes	Phosphor Bronze (A,C,D,E)	Sn–1.25 to 10, P–.01 to .50 Cu–Balance	Chemical hardware, Bourdon tubing, electrical contacts, flexible hose, pole line hardware	*Cadmium Free Alloys* SILVALOY 300, 380, 450 and 255 SIL-FOS Series *Cadmium Alloys* EASY-FLO & EASY-FLO 45 and 35
Silicon Bronzes	Silicon Bronze (A,B) Silicon Aluminum Bronze	Si–1.5 to 3, Cu–Balance Si–2.0, Al–7.25, Cu–Balance	Hydraulic tubing, marine hardware, chemical equipment	*Cadmium Free Alloys* SILVALOY 600 and 505 *Cadmium Alloys* EASY-FLO & EASY-FLO 45 and 35 EASY-FLO 3
Aluminum Bronzes and Aluminum Brasses	Aluminum Bronze (5%, 8%) Aluminum Silicon Bronze Nickel Aluminum Bronze	Al–5 to 8, Cu–Balance Al–7, Si–2, Cu–Balance Al–9.5, Ni–5, Fe–2.5, Mn–1, Cu–Balance	High strength forgings, pole line hardware, marine fittings, heat exchanger tubing	*Cadmium Free Alloys* SILVALOY 505, 501 and 600; TRIMET 259 *Cadmium Alloys* EASY-FLO 3; TRIMET 258
Cupro-Nickels	Cupro-Nickel (10%, 30%)	Ni–10 to 30, Fe–0.4 to 1.3, Cu–Balance	Marine piping and heat exchangers	*Cadmium Free Alloys* SIL-FOS Series w/10% Ni or less SILVALOY 603 and 450 *Cadmium Alloys* EASY-FLO & EASY-FLO 45 and 35
Nickel-Silvers	Nickel-Silver { 65-18 55-18 65-15 65-12	Ni–10 to 18, Zn–17 to 25, Cu–Balance	Plated flatware and holloware, camera parts, optical goods, costume jewelry	*Cadmium Free Alloys* SILVALOY 600, 202, 300, 380, 505 and 450 *Cadmium Alloys* EASY-FLO & EASY-FLO 45 and 35
Beryllium Copper	1 to 2% Beryllium Copper Cu–Balance	Be–1.9, Ni or Co–0.2 bridges, surgical tools, bolts,	Springs, diaphragms, contact Braze 560 and 720 spark resistant tools	*Cadmium Free Alloys* Handy Flux Type A-1 For Be-Cu to Steel use SILVALOY 505 or TRIMET 259 *Cadmium Alloys* EASY-FLO 3, EASY-FLO 45 or TRIMET 258

*Call our technical team for other possible alloy suggestions.

This table is intended to cover only a few typical applications. Many specific cases exist other than those listed. We invite your inquiry on any brazing problems. Inquire for specific recommendations when brazing copper and copper alloys to dissimilar metals.

Recommended Fluxes**	Recommended Atmospheres		Remarks
	Type	Maximum Dew Point	
None required with SIL-FOS, SIL-FOS 5 or FOS-FLO; Handy Flux or Handy Flux Type LT with EASY-FLO & SILVALOY alloys	Lean or Rich Exogas Reacted Endogas Dissociated Ammonia Vacuum	+20°F/–6.7°C +20°F/–6.7°C +20°F/–6.7°C	To avoid embrittlement, electrolytic tough pitch copper should not be brazed in hydrogen-containing atmospheres. Handy Flux Type LT is beneficial for long furnace brazing cycles.
Handy Flux, Ultra Flux or Handy Flux Type LT	Purified, Lean Exogas Reacted Endogas Dissociated Ammonia	+10°F/–12°C +10°F/–12°C +20°F/–6.7°C	In furnace brazing, flux may be used with the atmosphere for good ''wetting'' by the brazing alloy.
Handy Flux, Ultra Flux or Handy Flux Type LT	Purified, Lean Exogas Reacted Endogas Dissociated Ammonia	–40°F/–40°C –20°F/–28.9°C +20°F/–6.7°C	In furnace brazing, flux may be used with the atmosphere for good ''wetting'' by the brazing alloy. The EASY-FLO alloys are preferred for furnace brazing to avoid dezincification of high zinc brasses.
Handy Flux, Ultra Flux	Purified, Lean Exogas Reacted Endogas Dissociated Ammonia	–40°F/–40°C –20°F/–28.9°C +20°F/–6.7°C	In furnace brazing, flux may be used with the atmosphere for good ''wetting'' by the brazing alloy. Keep brazing cycles short to minimize lead pickup in the brazing alloy. Leaded brasses must be stress relieved before brazing to avoid intergranular cracking. Heat uniformly. The EASY-FLO alloys, SILVALOY 560 or SILVALOY 603 are preferred for furnace brazing to avoid dezincification of high zinc brasses. Furnace brazing of leaded brasses containing more than 5% lead is not recommended.
Handy Flux, Ultra Flux or Handy Flux Type LT	Purified, Lean Exogas Reacted Endogas Dissociated Ammonia	–40°F/–40°C –20°F/–28.9°C +20°F/–6.7°C	In furnace brazing, flux may be used with the atmosphere for good ''wetting'' by the brazing alloy. The EASY-FLO alloys are preferred for furnace brazing to avoid dezincification of high zinc brasses.
Handy Flux, Ultra Flux or Handy Flux Type LT	Lean or Rich Exogas Reacted Endogas Dissociated Ammonia Vacuum	+20°F/–6.7°C +20°F/–6.7°C +20°F/–6.7°C	The dew point and CO_2 content of the recommended atmospheres are not critical for phosphor bronzes, but flux may be required with the atmosphere for good ''wetting'' by the brazing alloy.
Handy Flux, Ultra Flux Handy Flux Type LT or Handy Flux Type A-1	Purified, Lean Exogas Dissociated Ammonia Vacuum	–40°F/–40°C –40°F/–40°C	In furnace brazing, flux may be used with the atmosphere for good ''wetting'' by the brazing alloy. Silicon bronzes must be stress relieved before brazing to avoid intergranular cracking and must be brazed below 1400°F (760°C) to avoid hot shortness. Use Handy Flux Type A-1 with silicon bronzes containing aluminum.
Handy Flux Type A-1	Purified, Lean Exogas Dissociated Ammonia Vacuum (Bronzes only)	–40°F/–40°C –40°F/–40°C	In furnace brazing, Handy Flux Type A-1 *should* be used with the atmosphere for good ''wetting'' by the brazing alloy. Dry H_2 will not reduce aluminum or titanium oxides.
Handy Flux, Ultra Flux or Handy Flux Type LT	Lean or Rich Exogas Reacted Endogas Dissociated Ammonia Vacuum	+20°F/–6.7°C +20°F/–6.7°C +20°F/–6.7°C	The dew point and CO_2 content of the recommended atmospheres are not critical for cupro-nickels but flux may be required with the atmosphere for good ''wetting'' by the brazing alloy. Cupro-nickels must be stress relieved before brazing to avoid intergranular cracking. Cupro-nickels containing more than 10% nickel should not be brazed with SIL-FOS or FOS-FLO type filler metals.
Handy Flux, Ultra Flux or Handy Flux Type LT	Purified, Lean Exogas Reacted Endogas Dissociated Ammonia	–40°F/–40°C –20°F/–28.9°C +20°F/–6.7°C	In furnace brazing, flux may be used with the atmosphere for good ''wetting'' by the brazing alloy. Nickel-silvers must be stress relieved before brazing to avoid intergranular cracking. Heat uniformly.
Handy Flux, Ultra Flux or Vacuum	Dissociated Ammonia	–40°F/–40°C	See Aluminum Bronzes. Flux is necessary to wet this material.

**For automated brazing, Handy Flux Type D or DB may be used where flux is required.

Stainless Steels: Brazing Materials Selection Chart

Group	AISI or Trade Designation	Nominal Composition—Percentages	Principal Uses	Recommended Brazing Filler Metals
Austenitic, Non-Hardenable†	302, 303 304, 316	Mn–2.0 max. Si–1.0 max. Plus 302 303 304 316 Cr 18.0 18.0 19.0 17.0 Ni 9.0 9.0 10.0 12.0 Max. Mo – 0.60 – 2.5 C 0.15 0.15 0.08 0.08 P 0.045 0.20 0.045 0.045 S 0.030 0.15 min. (or Se) 0.030 0.030	Chemical processing equipment, architectural trim	SILVALOY 505, EASY-FLO 3, SILVALOY 630, SILVALOY 404
			Cooking utensils and hospital equipment	SILVALOY 403, SILVALOY 630, SILVALOY 404, SILVALOY 505, SILVALOY 560
			Elevated temperatures (700°F/370°C max.)	SILVALOY 541, HI-TEMP 095, HI-TEMP 870
			Heat exchangers	LITHOBRAZE 925, LITHOBRAZE 720
			Vacuum tubes	PREMABRAZE 130, HI-TEMP 095, HI-TEMP 870
	321 & 347	Cr–18.0 C–.08 max. Ni–11.0 P–.045 max. Mn–2.0 max. S–.030 max. Si–1.0 max. Fe–Bal. (321 only) 5xC–Ti min. (347 only) 10xC–Cb+Ta min.	High temperature service (800-1500°F/425-815°C) or for max. corrosion resistance	PREMABRAZE 130
			Aircraft hydraulic tubing	SILVALOY 541
			Cryogenic apparatus	SILVALOY 505, EASY-FLO 3
Ferritic, Non-Hardenable	430	Cr–16.0 P–.040 max. Mn–1.0 max. S–.030 max. Si–1.0 max. Fe–Bal. C–.12 max.	Decorative auto trim and kitchen sinks	SILVALOY 630, SILVALOY 404, SILVALOY 559
			Nitric acid tanks	Silver brazing not recommended
	446	Cr–25.0 P–.040 max. Mn–1.5 max. S–.030 max. Si–1.0 max. N–.25 max. C–.20 max. Fe–Bal.	Resistance to high temperature scaling	SILVALOY 541 (700°F/370°C max. joint service)
				Premabraze 130 (1500°F/815°C max. joint service)
			Resistance to sulphur bearing gases or compounds	Premabraze 130
Martensitic, Hardenable	403, 410	Cr–12.25 P–.040 max. Mn–1.0 max. S–.030 max. C–.15 max. Fe–Bal. (403 only) Si–0.5 max. (410 only) Si–1.0 max.	Steam turbine blades	SILVALOY 630, SILVALOY 403, SILVALOY 404
			Jet engine compressor blades	SILVALOY 541
	440A	Cr–17.0 P–.040 max. Mn–1.0 max. S–.030 max. Si–1.0 max. Mo–.75 max. C–.60-.75 Fe–Bal.	Cutlery and surgical tools	SILVALOY 630
Precipitation, Hardenable	17-7 PH and PH 15-7 Mo	Ni–7.0 Al–1.1 Mn–1.0 max. Fe–Bal. Si–1.0 max. C–.09 max. (17-7 PH only) Cr–17.0 (PH 15-7 Mo only) Cr–15.0, Mo–2.5	Aircraft and missile honeycomb panels	Lithobraze 925
	17-4 PH	Cr–16.5 Cu–4.0 Mn–1.0 max. Ni–4.0 Si–1.0 max. Cb+Ta–0.30 C–.07 max. Fe–Bal.	Aircraft and missile components	Lithobraze 720
				SILVALOY 505, Easy-Flo 3
				SILVALOY 541
	AM-350	Cr–16.65 C–.09 Ni–4.50 Si–.35 Mo–2.85 N–.10 max. Mn–.75 Fe–Bal.	Aircraft panels	Lithobraze 925
			Aircraft hydraulic tubing	Lithobraze 720

†Easy-Flo, Easy-Flo 45, Silvaloy 560 and Easy-Flo 35 may be used satisfactorily on any of the 300 series stainless steels provided the joint is protected from exposure to moist conditions or chlorides. See Lucas-Milhaupt Technical Bulletin T-9.

This table is intended to cover only a few typical applications. Many specific cases exist other than those listed. We invite your inquiry on any brazing problems. Inquire for specific recommendations when brazing stainless steel to dissimilar metals.

Recommended Fluxes*	Recommended Inert-type Furnace Atmospheres**	Remarks
Handy Flux, Ultra Flux Handy Flux Type B-1 or Ultra Black Flux	Not necessary when flux is used. Dry hydrogen or vacuum without flux (SILVALOY 630 only)	The compatability of the brazing alloy with the chemical environment must be checked. SILVALOY 630 provides a better color match than Easy-Flo 3. Brazing alloys containing cadmium should be avoided for food handling applications.
Handy Flux, Ultra Flux, Handy Flux Type B-1 or Ultra Black Flux	None or dry hydrogen, vacuum (Except with SILVALOY 541)	Flux sometimes used with atmosphere in furnace brazing.
None	Argon or dry hydrogen, vacuum	The lithium content of these alloys imparts self-fluxing properties in a protective atmosphere.
Handy Hi-Temp Flux Boron Modified, or none	Not necessary when flux is used. Argon, vacuum or dry hydrogen without flux	For lower temperatures (700°F/370°C max.) and specific corrosion environments, Lithobraze 925 and Lithobraze 720 may be suitable.
Handy Flux Type B-1, Ultra Black Flux or Handy Flux Type A-1	None or dry hydrogen None	Flux sometimes used with atmosphere in furnace brazing. **Note:** 347 is preferred over 321 for brazeability. Handy Flux Type A-1 actively fluxes the titanium oxides formed on Type 321 stainless steel.
Handy Flux, Ultra Flux or Handy Flux Type B-1	Not necessary when flux is used. Dry hydrogen or vacuum without flux (SILVALOY 630 only)	SILVALOY 630 prevents interface corrosion. See Lucas-Milhaupt Technical Bulletin T-9.
Handy Flux Type B-1 or Ultra Black Flux	None or dry hydrogen	Flux sometimes used with atmosphere in furnace brazing.
Handy Hi-Temp Flux Boron Modified, or none	None or dry hydrogen, vacuum	Flux required for brazing in air. Flux not required in atmosphere.
Handy Flux, Ultra Flux, Handy Flux Type B-1 or Ultra Black Flux	None or dry hydrogen	SILVALOY 630 prevents interface corrosion. SILVALOY 403 and SILVALOY 404 resist interface corrosion. See Lucas-Milhaupt Technical Bulletin T-9. Flux sometimes used with atmosphere in furnace brazing.
Handy Flux, Ultra Flux, Handy Flux Type B-1 or Ultra Black Flux	None or dry hydrogen, vacuum without flux	SILVALOY 630 prevents interface corrosion. See Lucas-Milhaupt Technical Bulletin T-9. Cadmium-free brazing alloys required for these uses.
None	Argon	Not subject to interface corrosion. May require nickel plating prior to brazing.
None	Argon	Not subject to interface corrosion.
Handy Flux, Ultra Flux, Handy Flux Type B-1 or Ultra Black Flux	None	For parts not subjected to sustained high temperature service.
Handy Flux Type B-1 or Ultra Black Flux	None or dry hydrogen	For service up to 700°F (370°C).
None	Argon	Filler metals not subject to interface corrosion.

*For automated brazing, Handy Flux Type D or DB may be used where flux is required.

**Dry hydrogen should be –60°F/–50°C dew point or drier.

Brazing With Aluminum Filler Metals

Aluminum filler metals are used to braze aluminum base metals using various methods, the most common being salt dip bath, vacuum, and flux (either torch or furnace). Aluminum brazing requires tighter process parameters than most brazing processes because of the close relationship between the melting point of the braze filler metal and the base metal.

Cleanliness is very important when brazing aluminum base metals. All oil, scale or heavy oxides from extrusion or rolling process must be removed prior to brazing. (Note: It is impossible to remove all oxides from aluminum due to its natural affinity to oxidize upon exposure to air.)

Filler metals for brazing aluminum are available in wire, powder and paste, foil and as clad sheet. Not all filler metals are available in all forms. Some may be very difficult to locate in small quantities domestically, if at all. Aluminum filler metals are also sometimes used to braze titanium alloys.

Filler Metal	AWS A5.8 Classification	AMS	Solidus		Liquidus		Nominal Composition				Remarks
			°F	°C	°F	°C	Al	Cu	Si	Zn	
AL 716	BAlSi-3	4184	970	521	1085	585	Rem	4	10	—	Available in wire and preforms. Wide melting range (less fluid) filler metal.
AL 718	BAlSi-4	4185	1070	577	1080	582	Rem	—	12	—	Available in strip, wire, powder, paste and preforms. Most fluid of the aluminum filler metals.
AL 719	—	—	960	516	1040	560	Rem	4	10	10	Available as a powder or paste.
AL 802	—	—	710	377	725	385	2	—	—	98	Available as wire and preforms. High temperature solder for aluminum.

Soldering Filler Metals

Solders are low melting filler metals that are used to join a wide variety of materials. Solders melt below 840°F (450°C), and so can only be used for low temperature applications. The process is generally performed using a torch, iron, or using furnace, wave or ultrasonic methods. Soldering generally requires a flux. Fluxes for soldering range from being noncorrosive to being very corrosive. Flux selection is based on the materials to be soldered and the melting temperature of the base metal.

Solder selection is dependent upon the base metals, corrosion resistance required, service temperature, and required strength and creep properties. These are just some of the more common solders that Lucas-Milhaupt offers. Call our customer service department for information on other alloys available.

Filler Metals	Solidus		Liquidus		Nominal Composition				Comments
	°F	°C	°F	°C	Sn	Pb	Ag	Other	
96.5 Sn/3.5Ag	430	221	430	221	96.5		3.5		Eutetic alloy. Wets Cu, Brass, Steel, SS.
95 Sn/5 Sb	452	233	464	240	95.0			5 Sb	For Cu to Cu. Good creep strength. Not for brass
63 Sn/37 Pb	361	183	361	183	63.0	37.0			Eutectic-highest strength of Tin/Lead alloy series.
60 Sn/40 Pb	361	183	374	190	60.0	40.0			Electronic solder.
50 Sn/50 Pb	361	183	421	216	50.0	50.0			Good general purpose alloy. Use either rosin or acid flux.
40 Sn/60 Pb	361	183	460	238	40.0	60.0			Good for preforms. Use acid flux.
95 Cd/5 Ag (Easy-Flo 053)	640	338	740	393			5.0	95 Cd	Hi temp. solder–good strength.
80 Au/20 Sn	536	280	536	280	20.0			80 Au	Low ductility alloy. Low vapor pressure alloy.
78.4 Cd/16.6 Zn/ 5 Ag (Easy-Flo 056)	480	249	600	316			5.0	78.4 Cd/ 16.6 Zn	Hi temp. solder–good strength.
97.5 Pb/2.5 Ag	579	304	579	304		97.5	2.5		Eutectic alloy–a homogenous alloy.
97.5 Pb/1.5 Ag/1 Sn	588	309	588	309	1.0	97.5	1.5		Good corrosion resistance in humid atmospheres.

Forms available: Most solders are available in powder, paste, wire, and strip forms. Some solders, such as the Au/Sn, are brittle in nature and are not available in some forms.

Brazing With Gold Filler Metals

Gold based filler metals are used to join steels, stainless steels, nickel based alloys and other materials, where ductility and resistance to oxidation or corrosion is necessary. Gold filler metals readily wet most base metals, including the super alloys, and are especially good for brazing thin sections due to their low interaction with the base metal. Most gold based brazing filler metals are rated for continuous service up to 800°F (425°C). Those containing nickel may be used at higher temperatures.

Filler Metal	AWS A5.8 Classification	AMS	Solidus		Liquidus		Nominal Composition				Comments
			°F	°C	°F	°C	Au	Ni	Pd	Other	
Premabraze 920	BVAu-8 Gr 1		2190	1199	2265	1241	92.0		8.0		Oxidation resistant, ductile For Mo, W, Ta & Super alloys
82 Au/18 Ni Premabraze 130	BAu-4	4787	1740	949	1740	949	82.0	18.0			For SS, Inconel, Kovar®, etc. oxidation resistance to 1500°F (816°C)
LM 131 Gr 1	BVAu-4 Gr 1		1740	949	1740	949	82.0	18.0			For SS, Inconel, Kovar®, etc. oxidation resistant to 1500°F (816°C) for vacuum application.
81.5 Au/ 16.5 Cu/2 Ni			1670	910	1697	925	81.5	2.0		16.5 Cu	For Cu, Ni, Mo/Mn. Remains ductile.
80 Au/20 Cu	BVAu-2 Gr 1		1635	891	1635	891	80.0			20.0 Cu	Lowest melting of Cu-Au alloys. Loses ductility above 200°F (95°C).
75 Au/20 Cu/ 5 Ag			1625	885	1643	895	75.0			20 Cu/ 5 Ag	Narrow melting range. Good for step-brazing.
70 Au/8 Pd/ 22 Ni	BAu-6	4786	1845	1007	1915	1046	70.0	22.0	8.0		For Super alloys and SS. High ductility and strength.
60 Au/37 Cu/ 3 In			1580	860	1652	900	60.0			37 Cu/ 3 In	Lower braze temperature than Cu-Au series.
60 Au/20 Cu/ 20 Ag			1535	835	1553	845	60.0			20 Cu/ 20 Ag	Narrow melting range. Useful for step-brazing.
50 Au/50 Cu			1751	955	1778	970	50.0			50 Cu	For Cu, Ni, Kovar® & Mo/Mn metallized ceramic.
Premabraze 500	BVAu-7 Gr 1	4784	2015	1102	2050	1121	50.0	25.0	25.0		High strength & oxidation resistance. Brazing Super alloys.
40 Au/60 Cu			1796	980	1832	1000	40.0			60 Cu	For Cu, Ni, Kovar® and Mo/Mn metallized ceramic.
37.5 Au/ 62.5 Cu	BAu-1		1815	991	1860	1016	37.5			62.5 Cu	For Cu, Ni, Kovar® and Mo/Mn metallized ceramic.
35 Au/65 Cu			1814	990	1850	1010	35.0			65 Cu	For Cu, Ni, Kovar® and Mo/Mn metallized ceramic.
35 Au/62 Cu/ 3 Ni	BAu-3		1785	974	1885	1029	35.0	3.0		62 Cu	Good for Ni, Mo, SS, Kovar® and Mo/Mn—low penetration.
30 Au/34 Pd/ 36 Ni	BAu-5	4785	2075	1135	2130	1166	30.0	36.0	34.0		High strength—good oxidation resist.—For Super alloys.

Forms available: Gold based filler metals are available in wire strip, powder, paste and preformed shapes.While generally available, inventory levels may be limited due to the high precious metal content. Please check with your customer service representative for specific delivery.

Kovar is a registered trademark of CRS Holdings.

Brazing With Nickel Filler Metals

Nickel based filler metals are used to braze ferrous and nonferrous high temperature base metals. These braze filler metals are generally used for their strength, high temperature properties and resistance to corrosion. Some filler metals can be used up to 1800°F (980°C) for continuous service and 2200°F (1205°C) for short time service. Nickel based filler metals melt in the range of 1630 to 2200°F (890 to 1205°C), but can be used at the higher temperature due to diffusion of the melting point depressant elements from the filler metal into the base metal.

Joints made with nickel based filler metals tend to be more brittle than joints made with other filler metals. Care must be taken when using nickel filler metals containing boron on thin sections due to the erosive nature of the molten filler metal and the ability of this material to alloy with the base metal. Time and temperature must be monitored very carefully to prevent the molten filler metal from perforating the base metal.

Filler Metal	**AWS A5.8 Classification**	**Solidus**		**Liquidus**		**Nominal Composition**						**Comments**
		°F	**°C**	**°F**	**°C**	**Cr**	**Si**	**B**	**Fe**	**Other**	**Ni**	
HI-TEMP® 720	BNi-1	1790	977	1900	1038	14.0	4.0	3.1	4.5	0.75 C	Remainder	Recommended for parts subjected to light stresses at elevated temperatures. Good corrosion and flow characteristics.
HI-TEMP 721	BNi-1A	1790	977	1970	1077	14.0	4.5	3.1	4.5	.06 max C	Remainder	Similar to above but of particular interest where higher carbon content is not permissible. Slower flow than Hi-Temp 720.
HI-TEMP 820	BNi-2	1780	971	1830	999	7.0	4.5	3.1	3.0	.06 max C	Remainder	Widely used low melting filler metal for furance brazing aircraft parts, medical devices and other food handling components. Good flow generous fillets, low base metal penetration are characteristics of this filler metal.
HI-TEMP 910	BNi-3	1800	982	1900	1038	–	4.5	3.1	1.5 max	.06 max C	Remainder	Flows freely and less sensitive to atmosphere dryness than the other filler metals. Better for tight/longer joints.
HI-TEMP 930	BNi-4	1800	982	1950	1066	–	3.5	1.85	1.5 max	.06 max C	Remainder	For stainless steels & Ni & Co base alloys with thin sections—Jet engine parts and Chemical Equipment. More sluggish and is better for wide gap applications.
HI-TEMP 932	BNi-6	1610	877	1610	877	–	–	–	–	11.0 P .06 max C	Remainder	For stainless steels & Ni & Co base alloys with thin sections–Jet engine parts and Chemical Equipment. For uses that demand high temp properties and good corrosion resistance at low processing temperatures.
HI-TEMP 933	BNi-7	1630	888	1630	888	14.0	–	–	–	10.1 P .06 max C	Remainder	Often used for brazing honeycomb structures, thin-walled tube assemblies, and for nuclear applications where boron can't be used. The addition of chromium gives it better high temperature and corrosion properties than Hi-Temp 932.

NOTE: Recommended atmosphere for all above is Dry Hydrogen (–60°F/–50°C) dew pt. or better; inert gases; vacuum.

Brazing With Trimets

Trimet material consists of two layers of braze filler metal clad onto a core of copper. Trimets are used for brazing carbides to ease the stresses that arise due to differences in thermal expansion between the carbide and the base metal when cooling from the brazing temperature. Trimet materials are available in various filler metal compositions and different ratios of filler metals to Cu. Trimet selection is dependent upon base metals, service temperature and carbide size. Brazing of small carbides (½ inch square (12.7 mm) or less) may not require the use of a Trimet, but its use on larger pieces has proven very beneficial in preventing cracking and warpage of the carbide.

Filler Metal	Solidus		Liquidus		Formulation
	°F	°C	°F	°C	
TRIMET® 245	1260	680	1290	700	SILVALOY 495 on both sides of copper in 1-2-1 ratio.
TRIMET 258	1170	630	1270	690	EASY-FLO 3 on both sides of copper in 1-2-1 ratio.
TRIMET 259	1220	660	1305	705	SILVALOY 505 on both sides of copper in 1-2-1 ratio.

Carbide Tool Tips: Brazing Materials Selection Chart

General Group	Recommended Brazing Filler Metals		Recommended Fluxes**	Remarks
	Small Carbides (0.5 sq. in., 12.7 mm^2 or less)	Large Carbides* (Greater than 0.5 sq. in., 12.7 mm^2)		
Tungsten Carbide (WC) with cobalt binders.	EASY-FLO 3 SILVALOY 252 SILVALOY 403 SILVALOY 404 SILVALOY 495 SILVALOY 505 SILVALOY 580 HI-TEMP 080 HI-TEMP 095 HI-TEMP 548	TRIMET 245 TRIMET 258 TRIMET 259	Handy Flux, Handy Flux Type B-1, Handy Hi-Temp Flux Boron Modified	The presence of nickel and manganese in the filler metals improves wettability. SILVALOY 403 and 404 are sluggish alloys with long melting ranges. They produce relatively thick joints which help to relieve residual stresses in the joint. When brazing carbides that are subsequently titanium nitrided use a filler metal that does not contain cadmium or zinc, such as SILVALOY 580.
WC with moderate additions of Titanium Carbide (TiC), Tantalum Carbide (TaC) or Niobium (Columbium) Carbide (NbC), with cobalt binder.	(As above)	TRIMET 245 TRIMET 258 TRIMET 259		
WC with high percentage additions of TiC, TaC, or NbC, and cobalt or nickel binder.	SILVALOY 404 SILVALOY 495 SILVALOY 580 HI-TEMP 080 HI-TEMP 095	TRIMET 245	Handy Flux Type B-1, Handy Hi-Temp Flux Boron Modified	
Complex carbides including chromium and molybdenum with nickel and/or cobalt or steel binders.	SILVALOY 404 SILVALOY 495 SILVALOY 580 HI-TEMP 080 HI-TEMP 095	TRIMET 245		

Trimets are also useful for brazing aluminum bronze/steel, preventing the diffusion of aluminum to the steel interface. They are effective for joining sintered powder parts and wire mesh assemblies where wicking is objectionable and restricted flow is desired.

*Alloy to be preplaced.

**Handy dispensable fluxes are recommended for use in automated brazing applications.

Copper Brazing Alloys

These Copper filler metals have excellent corrosion resistance and high electrical and thermal conductivity. Lucas-Milhaupt stocks many copper-based filler materials including oxygen-bearing, oxygen-free and speciality alloys in wire, strip, paste and powder forms.

Filler Metal	AWS A5.8 Classification	Solidus		Liquidus		Nominal Composition					Comments
		°F	°C	°F	°C	Cu	Zn	P	Sn	Other	
CDA 101 (OFE)		1981	1082	1981	1082	99.99					For furnace brazing of steel, SS and Ni-based alloys
CDA 102	BCu-3	1981	1082	1981	1082	99.95					Joining of Ferrous, Ni-based and Cu-Ni alloys. Free flowing.
CDA 110	BCu-1b	1981	1082	1981	1082	99.9					Joining of Ferrous, Ni-based and Cu-Ni alloys. Free flowing.
CDA 510		1750	953	1920	1048	95		0.3	4.7		Use on steels where brazing temperatures lower than Cu are needed.
CDA 521		1620	881	1882	1026	92		0.3	7.7		Use on steels where brazing temperatures lower than Cu are needed.
CDA 681	RBCuZn-C	1590	865	1630	887	58	40		1	1 Fe	Joining of ferrous, copper and nickel alloys. Fluid alloy.

Handy One® Family of Flux Cored Brazing Materials

Flux cored materials can be used to simplify and improve most metal joining operations because it eliminates a separate fluxing operation, and reduces the brazing cycle time. In addition, our tests indicate that joints made with flux cored materials are higher quality and significantly stronger due to a consistent flux application and the subsequent reduction in flux inclusions (or voids) at the interface.

We offer a variety of flux cored materials for most general purpose brazing applications. We also offer several flux options so we can tailor a product to your application, heating method and joint configuration.

Filler Metal	AWS A5.8 Classification	Solidus		Liquidus		Nominal Composition					Comments
		°F	°C	°F	°C	Ag	Cu	Zn	Sn	Ni	
SILVALOY® 300	BAg-20	1250	675	1410	765	30	38	32			General purpose filler metal for joining ferrous and non-ferrous metals. Sluggish flow, enables filling large gaps. Not recommended for stainless.
SILVALOY 380	BAg-34	1200	648	1330	720	38	32	28	2		A Free flowing filler metal used with ferrous and non-ferrous base metals.
SILVALOY 505	BAg-24	1220	659	1305	707	50	20	28		2	Excellent general purpose alloy. Joins Ni and Fe based alloys, carbides and Stainless steel.
SILVALOY 560	BAg-7	1145	618	1205	651	56	22	17	5		Lowest temperature, Cd-free, silver brazing filler metal. Good color match for Stainless steel.

Aluminum wire and rings are also available with a variety of fluxes including corrosive and non-corrosive formulations.

Filler Metal	AWS A5.8 Classification	Solidus		Liquidus		Nominal Composition				Comments
		°F	°C	°F	°C	Al	Cu	Si	Zn	
Al 718	BAlSi-4	1070	576	1080	582	88		12		Most fluid of the aluminum filler metals.
Al 802		710	376	725	385	2			98	High temperature solder for joining aluminum.
Al 822		800	426	900	482	22			78	

Brazing and Soldering Pastes

Paste products consist of an atomized filler metal powder, a flux (when necessary) and a binder to hold the components together in suspension. Pastes, like preforms, are advantageous because with the correct dispensing equipment, tight control can be made on material usage. This can reduce your unit costs and yield consistent high quality joints. And because pastes are essentially formless in nature, one paste product could be suitable for a wide variety of joint configurations.

Additional advantages of pastes include the ability to control so many of the performance characteristics. For example, the viscosity or thickness of the paste can be modified for your particular dispensing requirements. Another characteristic that can be adjusted is the size of the filler metal powder, and we offer a range of particle sizes to provide the best balance between cost and performance. Paste can also be formulated to behave differently during the heating cycle. This is referred to as the "slump" or restrictiveness of the product.

Because we offer so many different options, it is recommended that a Lucas-Milhaupt Application Engineer is involved in the selection of the paste. Discussion on the specifics of your operation enables us to recommend the most suitable paste formulation.

Lucas-Milhaupt offers a number of flux-binder systems for most brazing and soldering applications including:

Flux Binder System	Active Range for Flux	Applications and Uses
HANDY FLO® 100 Series	550°C – 900°C 1100°F – 1650°F	General purpose flux binder systems for use with most common brazing alloys in torch, induction and resistance brazing operations.
HANDY FLO 200 Series	800°C – 1200°C 1500°F – 2200°F	Designed for higher temperature brazing applications in the 1500° to 2200° F Range. For use in torch, induction, resistance brazing operations.
HANDY FLO 300 Series	Flux Free	Exceptionally clean-burning system for controlled atmosphere and vacuum brazing operations. For use with High Purity or VTG brazing alloys.
HANDY FLO 400 Series	Flux Free	High temperature furnace binder system for brazing in exothermic, dissociated ammonia and vacuum. Typically used with Ni, Cu and bronze brazing alloys.
HANDY FLO 600 Series	550°C – 900°C 1100°F – 1650°F	The HANDY FLO 600 series is a clean-burning, furnace brazing binder system for use with the CuproBraze® alloys for joining copper and brass radiators.
HANDY FLO 700 Series	500°C – 600°C 930°F – 1100°F	Flux binder series for use with aluminum brazing alloys in open-air (torch, induction) operations. Available in both corrosive and non-corrosive formulations.
HANDY FLO 800 Series	150°C – 315°C 300°F – 600°F	Low temperature, flux binder systems for soldering applications under 450°C / 840°F. For use in open-air applications including torch, induction, resistance, infrared and oven. Easy clean up with a water rinse.

These flux binder systems are blended with an appropriate filler metal powder to form a completed paste product. For additional information or assistance in selecting the right combination of flux binder and filler metal, please contact our Technical Services Department at 414-769-6000 or via email at info@lucasmilhaupt.com.

CuproBraze is a registered trademark of the International Copper Association, Ltd.

Technical support services.

Lucas-Milhaupt is not only the leading supplier of brazing and soldering products and services, we are your complete source for technical information and assistance. A full staff of chemists, metallurgists and engineers are on hand to provide technical support for our customers.

Customer assistance.

Our technical support staff assists customers in solving their brazing and soldering problems by recommending appropriate alloys and offering various alternatives for their applications. This is accomplished through test brazing of customer components, examination of previously brazed assemblies, and through feasibility studies that explore the options available and the resulting benefits.

Brazing audits.

A Lucas-Milhaupt brazing audit involves a thorough examination of a customer's entire material joining operation by a member of our technical service team. Upon completion of the audit, a written report is furnished, offering recommendations to improve overall operating efficiencies and costs.

Training seminars.

Customers can take advantage of two different Lucas-Milhaupt seminars designed to meet their specific metal-joining needs.

"Fundamentals of Brazing/Design Course"—To adapt to the needs of students who desire both the basics and design aspects of brazing, Lucas-Milhaupt has combined two popular courses into one. This two and a half day seminar combines elements from the *Fundamentals of Brazing* and *Brazing and Soldering by Design*. Covered are all important aspects of brazing design and production with the accent on evaluation and solution of actual problem assemblies brought in by students as well as classic examples. The course objective is to provide designers, manufacturing and quality engineers, production managers, supervisors and operators with the information necessary to increase brazing/soldering efficiency, reduce and control variable costs and eliminate rejects.

Course sections and disccussions are tailored to specific customer requirements and all sessions are taught by members of Lucas-Milhaupt's Technical Services Group.

"Road Show"—We bring the seminar to you with this training session performed right in a customer's plant. We'll work with you to tailor this fundamentals course to meet specific needs and requirements.

Customized Brazing & Soldering Products

At Lucas-Milhaupt, we supply a vast selection of filler metals and forms because each metal-joining application has requirements that may make paste, preforms or wire the most appropriate for that job. The key is knowing the advantages of each, and that's where Lucas-Milhaupt can help. Because we offer hundreds of filler metals and forms, we're able to be totally objective when recommending solutions for your metal joining needs.

Dispensable Fluxes

In addition to formulated pastes, we've developed a family of highly concentrated dispensable fluxes for use with automatic dispensing systems. These products offer several performance advantages and are more environmentally friendly than traditional fluxes. Additional advantages include a reduction in material cost because less flux is required to complete the joint. Also, because these products are dispensed from automated systems, labor associated with mixing and application is eliminated. Uniform volume and placement of flux deposits also improves the joint quality.

Material dispensers.

Automatic paste and flux dispensers are offered in several different models depending upon the level of automation your production operation requires. Through the use of dispensing equipment you can fully control the application of braze paste or flux from position and size of the deposit to the frequency and speed of application. This results in greater efficiency and management of costs. Options include fully automatic systems as well as semi-automatic and manual dispensers.

Section 5: Available Reference Materials

Free Technical Literature
The following literature on brazing is available upon request from Lucas-Milhaupt. Call (414) 769-6000 in the U.S. and (416) 675-1860 in Canada.

Technical Data Sheets
There is a technical data sheet for most Lucas-Milhaupt brazing filler metals. The data sheet furnishes typical information on the properties and performance characteristics of the filler metal with various brazing conditions and base metal combinations.

Technical Bulletins
Bulletin T-1: Characteristics of the several types of silver brazing filler metals (Part 1)
Bulletin T-2: Characteristics of the several types of silver brazing filler metals (Part 2)
Bulletin T-3: Strength of brazed joints (Part 1)
Bulletin T-4: Strength of brazed joints (Part 2)
Bulletin T-5: Design of brazed joints with silver filler metals from the standpoint of stress distribution
Bulletin T-5 Supplement: Stress analysis of brazed joints
Bulletin T-6: Silver filler metal brazing and its relationship to the heat treatment of the parts joined
Bulletin T-7: Expansion and contraction in filler metals for silver brazing
Bulletin T-8: Fluxes for silver brazing filler metals
Bulletin T-9: Interface corrosion in brazed joints in stainless steel
Bulletin T-10: The oxidation characteristics of some silver filler metals in the 500°F to 1100°F temperature range
Bulletin T-11: Solution and penetration of stainless steels by various brazing filler metals
Bulletin T-12: Brazing Heating, Air Conditioning and Refrigeration Assemblies
Bulletin T-13: Improvement in Joint Quality and Reduction of Flux Usage with Ag Based HANDY ONE Products
Bulletin T-14: Effects of Joint Clearance on the Capillary Rise of a Molten Filler Metal
Bulletin T-15: Brazing and Nickel Based Brazing Filler Metals

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