Induction Brazing and Soldering

By Stanley Zinn, Induction Consultants • June 2010

Introduction

Induction heating lends itself to brazing and soldering because of its ability to heat selectively, rapidly and consistently. The induction process reduces part distortion, annealing and damage to the metal surface. Induction heating can also be applied to a wide variety of materials including ceramics, plastics and composite materials. For ceramics and plastics, it is necessary to apply a surface metallization before joining.

There are several methods of joining metals using a filler metal. The most common of these are brazing and soldering. In both cases, two metals are joined by adding a third filler metal which, when melted, forms an intermetallic layer between the two parts. This layer is formed by interaction of the alloy with the base metals being joined.

Soft solders are generally considered filler metals with a melting temperature in the range of 360º -500ºF *(182-260ºC)*. Most brazing utilizes filler metals with melting points that flow freely from 1150-1600ºF *(620-870ºC)*. In all cases however, the basic requirements for producing a good joint are the same:

1. A properly designed joint with good fit and proper clearances
2. Clean metal surfaces
3. Selection and application of flux
4. Proper alloy selection
5. Alignment of surfaces to be joined
6. Uniform heating of both parts

Joint Design for Induction Heating

The strength of a soldered or brazed assembly is dependent on the shear area or bonding surface between the two parts being joined, the strength of the alloy and the gap between the parts being joined. As can be seen in Figure 1, silver alloys can obtain strengths of 100,000 lbs. per sq. inch where the

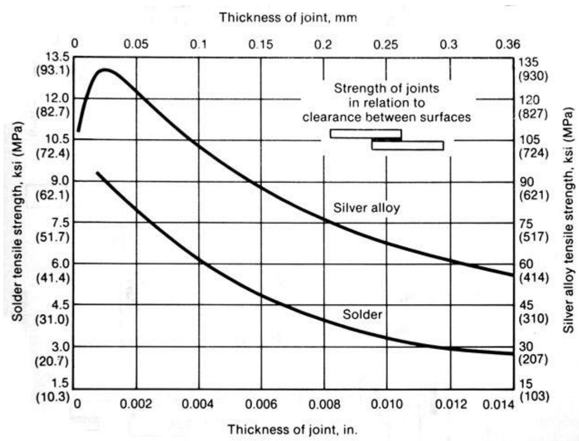

Figure 1

clearance gap is in the range of 0.001 to 0.003 in. For soft solder alloys, (the lower curve) strengths can be as high as 9,000 lbs. per sq. inch, with a clearance of 0.001”. The larger the gap between the two components, the lower the strength will be. This is due to the fact that as the gap widens, strength is dependent not on the shear area of the joint, but on the alloy itself.

With regard to joint clearance, it can be seen that maximum strength is achieved when there is a gap of .001” to .003”on each side. A fillet at the solder edge is useful in determining that the alloy has flowed through the joint. However, the fillet does not add strength to the joint and therefore, is important only in food or pharmaceutical applications where a porous joint might provide an area for bacterial growth.

Brazing and soldering alloys flow through the joint areas by capillary action. The alloy should be positioned so that it runs *through* the joint. This may involve feeding the alloy from a location farthest from the heat. The alloy can then pull through the joint to the heated area. Interference fits or knurled surfaces limit the flow by capillary action and therefore, by restricting alloy flow, reduce the strength of the joint.

The two basic joints are lap and butt, with the lap joint providing a greater shear area with resultant greater strength. All other joints are modifications of these two. The strength of the butt joint is limited by the thickness of the thinner member. For maximum strength, good lap joint design should provide an overlap of at least three (3) times the thickness of the thinner member. The greater the overlap of the two parts, the stronger the joint.

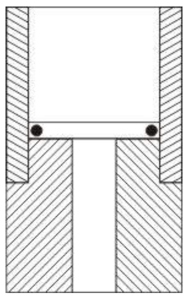

Figure 2A

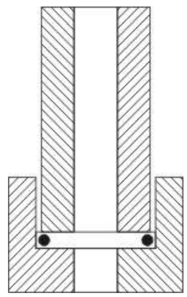

Figure 2B

Positioning of the alloy should also be considered when designing a solder or brazing joint. Where possible, the alloy should be placed in a location where it will run through the joint. This may entail feeding the alloy from a location away from the area of greatest heat. Gravity will aid capillary action in the flow of the alloy. In Figure 2A, the alloy is inside the tube but there is no way to ensure that it is in contact with the heated joint area. Poor alloy placement creates bad joints. A better location for the alloy would be as shown in Figure 2B. In this case, pressure by a weight or spring would have to be applied at the top of the tube to take up the space occupied by the alloy as it melts.

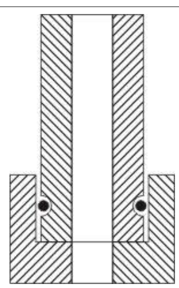

Figure 2C

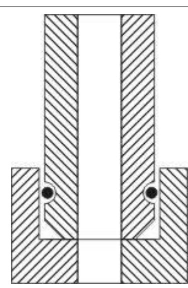

Figure 2D

To minimize the distance alloy must travel after melting, particularly where a large area is to be joined, it is sometimes advantageous to provide a groove where the alloy may be placed during assembly. Depending on its location, this groove can act as a reservoir of filler metal (Figure 2C) or a stop-off for the filler. A groove of this type is good for a deep joint for which a large surface area must be fed. This also ensures that the alloy is in proper position with regard to the joint. In many cases, it is desirable to restrict the flow of alloy. In this case, a flare or chamfer (Figure 2D) will break the capillary path and stop the alloy from going further.

Where alloy preforms are located exposed directly to the induction field, they may heat at a rate exceeding the rest of that at the joint area. This is due to the fact that completed rings form an ideal induction path. Rings should not be complete circles and preferably, should be shielded from the induction field by the joint design.

Clean metal surfaces

Alloys will not flow unless the factors necessary for capillary action are achieved. “Capillary action is a force resulting from a combination of adhesion, cohesion and surface tension in liquids, which are in contact with solids. When the cohesive force is greatest, liquids tends to rise in the joint area. In effect, fluids tend to fill gaps through gravity, surface tension and wetting of the surfaces.”

Wetting, a force of adhesion between solid and liquid, occurs when the force of the liquid is greater than the cohesive force. Wetting depends on the liquid alloying with the surface of the solid. Alloy selection must be decided on its ability to wet with the materials being joined.

Dirt or particles in the joint area will restrict capillary flow and prevent the alloy from flowing throughout the joint area. For this reason, both part surfaces should be fee of oil, dirt, grit, metal chips or similar contamination.

Cleaning can be accomplished chemically using caustics or solvents compatible with the material to be removed. Solvent cleaning is capable of removing oil, grease, metal chips and other contaminants. Alkaline cleaning is also satisfactory for removing oily, semi-solid or solid soils from steel. It is generally satisfactory for removing most cutting and grinding fluids, grinding and polishing abrasives. If necessary, an acid pickle should follow to remove rust and scale. Trying to remove these by abrasion will create a fine abrasive dust, which may be driven into the part surface. Suitable methods will vary based upon the part configuration and production requirements. These include spray wash, bath and tumbling.

The length of time that cleaning remains effective depends on the metal involved, the atmospheric conditions and the amount of handling the parts may receive. Length of time and method of storage can also affect oxidation of the part surfaces. It is strongly recommended that the soldering or brazing be accomplished shortly after the cleaning operation.

Selection and application of flux

Flux is not a cleaning agent! It cannot perform the functions of a proper cleaner. Flux is used solely to reduce the oxides on the surfaces to be joined and encapsulates the alloy as it flows, to preclude air contamination of the joint**.**

Flux can be acid-based or non-active such as a resin and is generally selected for its ability to work with the materials being joined. The more stable the oxide (i.e. aluminum) the more reactive the flux should be. The flux must be active at the flow temperature of the alloy since oxidation increases with temperature. In some cases, the flux is applied to the entire heat-affected area. Since flux prevents oxidation, the coated area will not oxidize and discolor or scale.

It should be noted that residues from the flux remain on the part subsequent to brazing. In the case of borax-based fluxes, when left to harden, this will leave a hard, glassy surface that is difficult to remove. It is always desirable to remove this residue as rapidly as possible. A light, misty spray of water on the part, immediately after the alloy solidifies, will remove most of the residue. A mildly active bath should follow to remove the balance. Following this, a water bath with a rust preventative should be used. Some chemical baths for flux removal are also available.

Coil Design

As in torch brazing, the parts to be joined must reach the same temperature at the same time to provide capillary action. Hotter areas will cause the alloy to move toward the hottest part of the assembly. This is further complicated not only by the largest mass in the assembly but by the material as well. Because of the differences in resistivity of materials and the fact that heating with a high frequency current is based on I^2R, different materials will heat differently in an induction field. The same current that flows in a steel part may not bring a similar piece, made of copper, to the equivalent temperature in the same interval of time. Therefore, the coil must be designed to deliver more current to the greater mass/ lower resistivity material, while still bringing the mating part to temperature at the same time.

This change in design of the coil requires placing either more turns at the greatest mass, or decreasing the coupling distance to the larger part so it receives more magnetic flux from the coil.

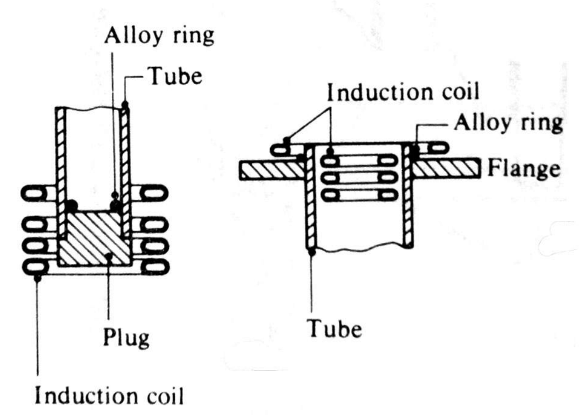

Figure 4

Typically, in a tool-brazing system where the steel has a lower resistivity than the tungsten carbide insert, as well as a greater mass, the coil is positioned lower on the tool to deliver more heat to the steel shank. See Figure 4.

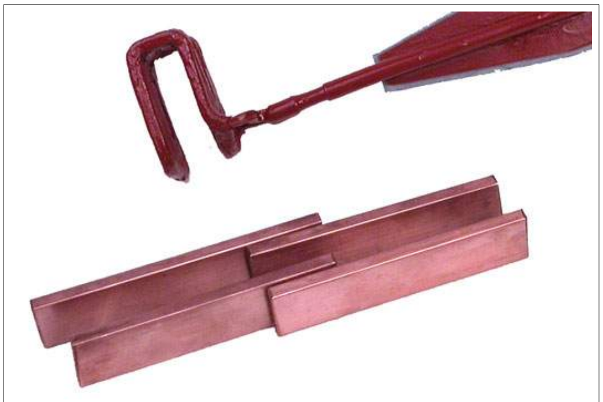

Figure 5

The strongest flux field and therefore the most heat is generated inside the coil. However, in many instances this is not feasible and it requires the coil to be designed in a "U" or channel coil shape (see Figure 5) so that it has accessibility to the assembly and can be removed after the brazing application. Though it is not the most efficient design, the end result, requiring more power, justifies the means.

Figure 6 shows a typical portable system for brazing electrical connections on large copper bars for motors. The open "U" inductor is easily placed and removed from the components for brazing in the field. Split or scissor type coils can be used but are limited to one or two turns due to mechanical limitations.


Figure 6

Most commercial brazing applications do not require high power and small variations in temperature are normal. The fixed mass of the components and therefore the temperature is normally controlled by either power or time. This allows multiple parts to be brazed simultaneously if sufficient power is available. Figure 7 shows the construction of a typical multi-place brazing coils. By modification of the coupling distance (opening the coupling on smaller parts), simultaneous brazing of non-similar components can also be achieved.

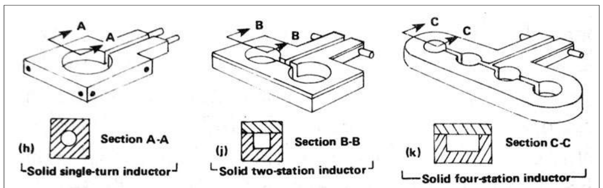

Figure 7

Vacuum or Atmosphere Brazing

As noted, many steels are preferentially brazed in vacuum, hydrogen, forming gas (90% N_2 and 10% H_2), Nitrogen or Argon. The purpose is to utilize the vacuum or gas as a deoxidizing agent while preventing the balance of the component from oxidizing due to heat transfer. The additional benefit of this technique is the elimination of flux resulting in a clean part that does not require cleaning subsequent to the joining operation.

The induction brazing of stainless steels can be accomplished in a vacuum or dry hydrogen atmosphere A typical system is shown in Figure 8. If an atmosphere is used, a dew point of –60°F or lower is required to prevent the chromium from being oxidized. This same approach may be used with Type 200 stainless steels if the dew point is kept very low. Precipitation–hardening stainless steels can also be brazed in dry hydrogen if there are no more than trace amounts of titanium or aluminum. These steels may also be brazed in vacuum if neither of these elements is in the steel.


Figure 8

Vacuum or gas atmospheres for brazing are generally used in a batch furnace but have the disadvantage of heating the entire component during the brazing cycle. In addition to affecting the metallurgical properties of the part, this process is time consuming and uses considerable space and energy as well.

Since the induction field can be highly localized, using induction in a vacuum chamber can minimize these problems. In practice, the chamber is evacuated to a suitable level (10^{-6} Torr where possible) and the chamber is backfilled with the desired gas. A partial pressure system maintains the gas at acceptable levels during the brazing cycle. Parts emerge from the system as clean bright assemblies after brazing.

Vacuum brazing chambers can be fitted with numerous automated fixtures to move the coil or part so that the joint area is within the coil. Rotary tables and lift rotate assemblies are sometimes provided for handling multiple parts. To minimize down time, where multiple assemblies must be processed, air locks at the entry and exit of the chamber, allow parts to be brought into, and exit from, the chamber, without contaminating the atmosphere. An example is shown in Figure 9.

Figure 9

Alloy Selection

There are a number of basic requirements for any filler metal (alloy) used in brazing:

1. The alloy must have a melting temperature below the melting point of the components being brazed.
2. The alloy must be able to "wet" to the materials being joined.
3. Flow characteristics of the filler material must be compatible with the joint clearance and be able to utilize capillary action for filling the joint area.
4. The alloy must be able to provide the strength and anti-corrosion resistance of the joint for the service required.

One of the most important characteristics of the filler metal is its ability to match the Thermal Coefficient of Expansion of the mating parts. The braze material must be sufficiently ductile to have a thermal expansion comparable to the metals being joined. These filler alloys then can tolerate a wider gap between components with minimal formation of porosity or brittle phases. When there is a difference in thermal expansion between the base metal and the filler metal, stress concentration and high residual stresses may result.

Subsequent to the brazing operation, the parts must remain in place until the alloy solidifies. Premature movement, while the alloy is still molten, may result in crystallization and a weak joint.

Typically, these stresses occur in the brazing of carbides to steel as required for cutting tools. In this case, stresses can be avoided by using a filler composed of a copper strip clad with the brazing alloy on both sides. This method minimizes stresses due to the low yield strength of the intermediate copper.

Brazing materials are available in a wide range of forms and must be selected to match the requirements of the manufacturing process. Typical forms are:

- Ingot/shot/pellets
- Wire (0.030-0.100")
- Sheet
- Foil (0.003-0.010")
- Preforms of any of the above
- Powder
- Pastes (a mixture of alloy and flux)

There are a large number of soldering alloys utilized for low temperature applications. These range from the standard lead-tin Eutectic, through gold bearing filler metals, or those with constituents of antimony, bismuth, cadmium, indium, lead, silver, zinc or tin. Each solder has a specific use and is tailored to the specific application. Brazing alloys, on the other hand, are generally comprised of silver, gold, palladium, aluminum, etc.

The filler metals used to braze low carbon steels are those listed in the AWS (American Welding Society) Bag and Bcu series. The silver bearing fillers are used because they melt and flow at comparatively low temperatures. Nickel-base alloys can also be used, particularly where greater joint strength and corrosion resistance are required. The copper bearing fillers melt at higher temperatures but are considerably less expensive. These are used primarily in joining copper or brass assemblies, or for steel components in a reducing atmosphere. The copper bearing alloys are also sluggish in their flow characteristics when melted, and tend to fill larger gaps and voids more easily than the silver-bearing alloys.

When the joint members are stronger than the braze material, stress concentration and high residual stresses may become critical factors. This is also a problem when differential contraction takes place, as when dissimilar materials are brazed. This is commonly the problem when brazing tungsten carbides for cutting tools. An intermediate layer of copper (which may be clad on both sides with the braze material) can minimize these problems due to plastic deformation in the copper.

Vacuum brazing requires filler metals that will not volatilize at brazing temperatures. Fillers with high vapor-pressure components, such as zinc or cadmium should not be used in these circumstances.

Differential Brazing

In many applications, adjacent components must be assembled. Yet, physical location may preclude simultaneous brazing of these parts. In addition, close proximity requires that the heating of one part does not influence the quality of the braze on adjacent parts. This is generally handled by using alloys with different melting points at each joint. Starting with the highest melting point alloy, succeeding brazes are made with lower melting point alloys.

Fixturing

At this point, fixturing of the assembly should be considered**.** The result of the joining operation is to produce a part whose characteristics (length, angularity, size, etc.) match a specific requirement. The purpose of the fixturing therefore is to hold these parts in a manner that will assure those characteristics until the brazing is accomplished.

Parts can be designed to be self-fixtured. Dependent on the components and their tolerances, some assemblies will hold relative position easily. If the shape and weight of the parts permit, the simplest way to hold parts together is by gravity. Another technique would be the possible use of spot welding to hold the parts in place. However, it should be noted that the welded area will not get alloy flow and therefore, this should not be included when considering required shear area.

Where self-fixturing is not feasible, consideration should be given to ease of assembly in the fixture, as well as determining if the completed assembly may be easily removed after joining.

Parts near the coil should be made of insulating materials compatible with the temperatures to which they will be exposed. Materials used in the fixture should be poor heat conductors, such as stainless steel, Inconel or ceramics. Poor conductors will pull less heat away from the joint area. In some cases, however, generally due to tolerances, metal must be used. It is important that the metal components be made of alloys that do not “wet” to the brazing alloy resulting in the part being brazed to the fixture. Titanium is often used for this type of locator. Where stainless steel must be used, 300 series non-magnetic stainless would be the material of choice.

Clamps of various types can be used to locate the assembly components and hold them in place during the brazing cycle. One concern is the heat transfer from the assembly being brazed to metal components of the fixture. Where these must be in contact, heat transfer can be minimized by using point or knife-edge contact with the part being heated. The comparative expansion rates of the components being joined and the metal holding fixture should also be considered so that misalignment can be minimized and further, allow parts to be easily removed from the fixture. Finally, attention should be paid to placement of the coil relative to the fixture. The coil should be rigidly mounted to the fixture to assure that it is always in the same position from assembly to assembly. Threaded studs or pads on the coil, mounted to the insulating components of the fixture, will assure repetitive joints from part to part.

In soldering and brazing operations, because of the splatter caused by boiling flux, the fixture components may become coated with the flux. This can prevent the easy and accurate assembly of subsequent parts. So long as the area being coated is not directly in contact with the joint itself, a coating of Vaseline or similar material should be applied to the fixture. When flux build-up appears to be a problem, the area can be easily wiped down and a new coating of Vaseline applied.

In some cases, it will not be possible to assemble the components while the joint area is within the coil. Accordingly, provision must be made to raise or lower the part, after assembly in the fixture, so that the area to be heated is within the coil. In some instances, it is simpler to raise or lower the coil itself into the proper location.

Jigs can be used to fulfill more than a brazing function. For example, it can serve as a heat sink or as a heat source. Graphite is often favored as a fixture material. It is inexpensive, easy to machine, a good thermal conductor and absorber of heat, and is not wetted by the majority of molten filler metals. Where parts must be slow cooled subsequent to brazing, as with ceramics, the graphite acts as a heat sink to modify the cooling time. Graphite also has the merit of absorbing trace oxygen in an oxidizing atmosphere to form CO and CO_2.

Dependent upon the fixturing required, brazing can be accomplished with rotary tables or in-line conveyor systems. These systems can be either continuous or indexing types.

Uniform Heating

Power densities for brazing and soldering are considerably lower than those used for heat treating applications. It is desired to have the heat penetrate through the joint and since the materials must be at the same temperature, a low power density is required so that the outer section of the joint does not overheat. For that reason, power densities for brazing and soldering range from 0.5 to 1.5 kW/in^2.

A generalized formula for determining approximate power required for brazing is:

$$P = WTC/0.95t$$

P = absorbed power in kW
W = pounds of material heated by the induction coil and by thermal conduction away from the Joint
T = temperature rise in degrees Fahrenheit
C = Specific Heat of the material
T = heating time to meet production requirements, in seconds

With respect to the alloy, capillary action will cause the alloy to flow toward the part with the highest temperature. Liquid alloys tend to flow in the direction of the hottest temperature. It is important therefore, that all components come to the brazing temperature at the same time. For this reason the coil should be designed to place greater heat close to the greatest mass. In addition, if there is a great difference in the resistivity of one material versus another, the part with the greatest resistivity will heat at a faster rate due to its I^2R loss. Balancing the heat between the components is usually an empirical endeavor. The coil can be moved closer to the greater mass or more coil turns can be located in this area.

An indication of the difference in temperature of the two parts can be seen in the movement of the flux. The flux will melt sooner and tend to flow toward the part with the greater heat.

Once this has become apparent, it is necessary to look for the flow of alloy in the joint. A properly processed assembly will have the alloy flow fully through the joint area. This can be readily seen as the alloy appears at the opposite side of the joint.

Normally, the time to heat at this point is sufficient and will be repeatable thereafter, as long as the applied power remains the same. In some instances however, because of the mass of the larger part and the position of the alloy it is necessary to heat for a longer period, enabling conduction to bring the joint to the brazing temperature. This soak period must be controlled in order to protect the part.

If the heat is put in at the same rate as is used to bring the part to temperature, the large mass will continue to heat beyond the flow temperature of the alloy. This could result in greater oxidation and the forming of scale. The power should be reduced at the flow temperature to allow soaking of the heat to the joint and preventing overheating of the outer component. This can be controlled, once parameters have been determined, either by a programmable temperature controller or with an optical pyrometer sighting on the part and controlling the power output of the power supply via a PID controller.

Brazing and Hardening in a single operation

In some applications, it is beneficial to incorporate the brazing and heat treatment of the material in a single operation.

Heat treatment can precede brazing. The brazing is done at the lowest temperature and the shortest time possible (per the table). Process times must be short to prevent possible problems with the steel.

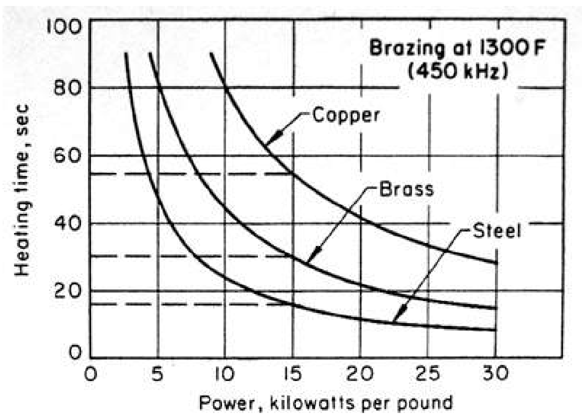

Figure 10

A preferred technique is that of selecting an alloy whose melting *and* solidification temperature are above the hardening temperature of the material. Once the alloy is melted and resolidification takes place, the part can then be quenched at any temperature without recrystallizing the brazing alloy. Short heat times in this system can be used to limit the hardness case depth. It should be noted that hardening phase transformations result in contraction and expansion of the joint. Allowance for variation in dimension due to these changes should be made in the fixture design. Hardness can also be affected (see Figure 10).

Susceptors

Where materials cannot be heated directly by the induction field, intermediate materials called Susceptors are often utilized.

Susceptors are materials that can be heated by induction and which pass on their heat by conduction, radiation or convection.

The most common of these materials is carbon graphite which, because of its high resistivity, heats extremely well in the induction field. Typically, where glass lenses must be soldered to a metal frame, the periphery of the glass is coated with a material, which will wet to the solder. Multiple lenses, with the mountings to which they are to be joined, are placed in a graphite fixture, which is then placed in an induction coil. The carbon susceptor heats readily in the induction field raising the assembled to the alloy flow temperature. The additional benefit of the susceptor, in this instance, is the slow cooling that results from the mass of the carbon after it is removed from the induction field. This greatly reduces stresses in the glass lenses reducing cracking and shattering.

A reducing atmosphere must be used to prevent oxidation of the carbon, and this in turn aids as a flux for the joining operation.

Base Metal	Condition	Before Brazing	After brazing At 635ºC (1175ºF)	After brazing At 705ºC (1300ºF)	After brazing At 760ºC (1400ºF)
Low-carbon steel.	Annealed	55-70 HRB	55-70 HRB	55-70 HRB	55-70 HRB
	Cold rolled	60-90 HRB	55-80 HRB	55-75 HRB	55-70 HRB
Low-alloy or low-carbon steel (0.4-0.5% C)	Annealed	90-100 HRB	90-100 HRB	90-100 HRB	May harden slightly
	Heat treated to 1030 MPa (150 ksi)	32 HRC	22-32 HRC	18-25 HRC	May harden slightly
Carbon and low-alloy tool steel	Hardened and tempered	50-65 HRC	28-32 HRC	20-25 HRC	May harden
High-speed steel	Hardened	65 HRC	59-63 HRC	46-50 HRC	--

Affect of brazing on hardness of adjacent areas

Bibliography

J. Davies and P. Simpson, *Induction Heating Handbook,* McGraw-Hill, Ltd. London, 1979

S. Zinn and L. Semiatin, *Elements of Induction Heating,* Electric Power Research Institute, Inc., Palo Alto, California, 1988

Armin Rahn, *The Basics of Soldering, John* Wiley and Sons, Inc., New York, 1993

Giles Humpston and David M. Jacobson, *Principles of Soldering and Brazing,* ASM International, Ohio, 1993

Mel M. Schwartz, *Brazing,* ASM International, Ohio, 1987

Brazing Manual, American Welding Society, Florida, 1975

Selecting Furnace Atmospheres? Think safety!, Metal Heat Treating, Jan/Feb. 1994, P. 48

Exploring the Basics of Brazing, Metal Heat Treating, Jan /Feb. 1994, P. 22

M. Karavolis, *Production of Precision clad self-brazing materials to achieve high yields and strong joints,* Industrial Heating, Dec. 1993, P. 47

A. Stanley Cross, *Precious metals can make priceless brazing alloys,* Heat Treating, April 1992, P. 43

R. K.Vackar, *Key to successful brazing,* ME, March 1982, P. 66

Handy and Harmon, Adv. *Brazing?,* ME, March 1982, P. 22

J. Gould, *Induction heating enhances hot pressure welding, Materials Progress, Oct. 1993, P. 11*

D. Buttner & J. O. McGeever, *What you should think about when you think about brazing.* Heat Treating, Oct. 1987, P.22

Fastening, Joining and Assembly, Machine Design, June 1992, P. 320

The Brazing Book, Handy & Harman Lucas-Milhaupt, Oct. 1996

Dr. J. F. Libsch, *Induction Brazing*, Modern Application News, Oct. 1994

H. D. Steffens, B. Wielage, and K. Biermann*, Modified High Temperature Brazing Techniques for Nickel Based Materials*, May 1989, P. 17

Exploring the Basics of Brazing, A Staff Report. As reported in Part One of "Exploring the Basics of Brazing" (see Metal Heat Treating, Jan./Feb. 1994)

Ann Severin, *Brazing of Carbon Steel*, Advanced Materials & Processes 12/97

Ronald Smith, Merle Thorpe, and Eric Lugscheider, *New Materials Increase Applications for Brazing – Part I: Process Considerations*, Industrial Heating, Sep. 97

Fastening & Joining, Part 2 Brazing processes, Machine Design Magazine, 1997

Diane L. Hallum, *Brazing: Welding's Cooler Cousin*, Forming & Fabricating, Sep. 1997