Brazing and Soldering

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Brazing

Brazing refers to a group of joining processes that produces the coalescence of materials by heating them to the brazing temperature in the presence of a brazing filler metal having a liquidus above 840°F (450°C) and below the solidus of the base metal, i.e. without melting of the base metal. The liquidus, or melting point, is the lowest temperature at which a metal or an alloy is completely liquid, and the solidus is the highest temperature at which a metal or an alloy is completely solid. Brazing is characterized by the distribution of a brazing filler metal between the closely fitted faying surfaces of the joint. With the application of heat, the brazing filler metal flows by capillary action, and is melted and re-solidified to form a metallurgical bond between the surfaces at the joint. Furnace brazing is the usual method of brazing Ni-/Co-base alloys, especially when high-temperature brazing filler metals are employed, and the information that follows will focus on furnace brazing.

The keys to successful brazing of Ni-/Co-base alloys are:

- Thorough cleaning and preparation of base metal surfaces
- Proper filler metal selection for the intended application
- Proper fit-up and freedom from restraint during brazing
- Proper atmospheric protection during brazing
- Minimal thermal exposure to avoid secondary precipitation in the base metal

Base Metal Surface Preparation

All forms of contamination such as dust, paint, ink, chemical residues, oxides, and scale must be removed from part surfaces prior to brazing. Otherwise, the molten brazing material will have difficulty "wetting" and flowing along the surface of the base metal. Surfaces must be cleaned by solvent scrubbing or degreasing and then by mechanical cleaning or pickling. Tenacious surface oxides and scales may require grinding. Once cleaned, the parts should be assembled as soon as possible using clean gloves to prevent subsequent contamination. It is important to note that proper cleaning techniques should be used on the entire component assembly prior to brazing, not just the surfaces being brazed.

Some high-temperature alloys may benefit from the application of a thin nickel flashing layer before brazing, particularly those alloys containing higher aluminum and titanium contents. This layer is normally applied by electroplating; electroless nickel deposits using nickel-phosphorus alloys are not recommended. Flashing layer thicknesses of up to about 0.001 in (0.025 mm) maximum are normally employed, depending upon the specific base metal alloy and the specific joint geometry.

Brazing Filler Metal Selection

Proper selection of a brazing filler metal for the intended application depends upon a number of factors, including component design, base metal alloy(s), and service environment. Brazing filler metals are typically classified according to chemical composition. HASTELLOY® and HAYNES® alloys may be successfully brazed using a variety of nickel-, cobalt-, silver-, copper-, and gold-based filler metals; some of the possible brazing filler metals are listed in Table 4. The exact alloying content of the brazing filler metal determines the temperature range between the liquidus and solidus, i.e. the melting temperature range. The magnitude of the melting temperature range indicates the potential filling capability, and a brazing filler metal with a larger melting range is generally more capable of filling a larger joint clearance. If the brazing filler metal melts at a specific temperature, it is referred to as a eutectic filler metal. As a result, eutectic filler metals have less filling capability and require tight joint clearances. Examples of eutectic filler metals are the AWS A5.8 BAg-8, BAu-4, and BCu-1 classifications.

Filler metals are commonly applied as a powder mixed with a liquid binder. The brazing filler metal powder can also be mixed with a water-based gel suspension agent to produce a paste. Filler metals are also available as foil and tape. Every effort should be made to confine the brazing filler metal to the joint area as any spatter upon non-joint surfaces could severely degrade the environmental resistance at that location, particularly if it is exposed to service temperatures above the melting point of the brazing filler metal. Since most brazing filler metals do not possess the same level of corrosion resistance as Ni-base corrosion-resistant alloys, it is preferable that brazing is used for joining only when the brazed joint will be isolated from the corrosive environment.

Nickel-based brazing filler metals can be utilized for high-temperature service applications up to 2000°F (1093°C). They generally have additions of boron, silicon, and manganese to depress the melting range and accommodate brazing at various temperatures. The boron-containing brazing filler metals are used for aerospace and other applications subject to high temperature and stress conditions. However, they are susceptible to the formation of brittle borides. These brazing filler metals may also contain chromium to provide for more oxidation-resistant joints.

Cobalt-based brazing filler metals are typically useful for achieving compatibility with Co-base alloys, and obtaining good high-temperature strength and oxidation resistance.

Silver-based brazing filler metals have been successfully used for brazing Ni-base corrosion-resistant alloys intended for service applications below approximately 400ºF (204ºC). They are known for excellent flow characteristics and ease of usage. Filler metals containing low-temperature constituents, such as zinc and tin, are difficult for furnace brazing since they will evaporate prior to reaching the brazing temperature. Most furnace brazing with silver-based filler metals should be conducted in an argon atmosphere. It should be cautioned that most Ni-base alloys are subject to stress-corrosion cracking when exposed to molten silver-rich compositions, so it is imperative that the base metal be stress-free during brazing when utilizing silver-based filler metals. This liquid metal embrittlement form of cracking occurs catastrophically at the brazing temperature.

Copper-based brazing filler metals tend to alloy rapidly with Ni-base alloys, raising the liquidus and reducing fluidity. Therefore, they should be placed as close to the joint as possible, and the assembly should be heated rapidly to the brazing temperature. Copper-based brazing filler metals are only suggested for joining components to be used at service temperatures below 950°F (510°C). Copper-based brazing filler metals that contain significant amounts of phosphorus should be used with caution since they tend to form nickel phosphides at the bond line that promote brittle fracture. Copper-based filler metals should not be used for brazing Co-base alloys.

Gold-based brazing filler metals are mostly used when joining thin base metals due to their low interaction with the base metal. They are also useful when good joint ductility and/or resistance to oxidation and corrosion are primary concerns.

For more detailed information on different brazing filler metal classifications, please refer to: *AWS A5.8M/A5.8, Specification for Filler Metals for Brazing and Braze Welding, American Welding Society*. There are also numerous proprietary brazing filler metals and alloy compositions that are commercially available. It is suggested that brazing filler metal manufacturers be consulted when selecting a filler metal for a specific base metal alloy or application.

Fit-Up and Fixturing

Since most brazing alloys flow under the force of capillary action, proper fit-up of the parts being brazed is crucially important. To facilitate uniform flow of the molten brazing filler metal through the joint area, joint gap clearances on the order of 0.001 to 0.005 in (0.025 to 0.125 mm) must be maintained at the brazing temperature. Excessive external stresses or strains imposed on the brazed joint during brazing may cause cracking, especially when brazing fluxes are involved. If possible, components should be brazed in the annealed condition (i.e., not cold worked).

Making use of appropriate joint fixturing is also helpful. Fixtures used in furnace brazing must have good dimensional stability and generally low thermal mass to facilitate rapid cooling. Metallic fixtures are limited in their ability to maintain close tolerances through repeated thermal cycles, and are relatively high in thermal mass. Accordingly, graphite and ceramic fixtures are normally better suited for use in high-temperature furnace brazing applications. Graphite has been widely used in vacuum and inert gas furnace brazing, and provides excellent results. However, graphite should not be used for fixturing in hydrogen furnace brazing without a suitable protective coating, as it will react with the hydrogen and possibly produce carburization of the parts being brazed. Ceramics are also used, but typically for smaller fixtures.

Protective Atmospheres and Fluxes

In addition to proper cleaning procedures prior to brazing, control of furnace environment and purity of the brazing atmosphere is vitally important to ensure proper flow characteristics of the brazing filler metal. Since most Ni-/Co-base alloys are designed to form tenacious oxide films, these same oxide films will cause problems during brazing if atmospheres are not rigorously controlled. Exclusion of oxygen, oxidizing gas species, and reducible oxide compounds from the furnace environment is required as oxygen derived from any source within the furnace can produce surface contamination in the joint area. Ni-based brazing filler metals, for instance, are commonly used in conjunction with vacuum, high purity argon, or hydrogen (reducing) furnace atmospheres. The interior of the furnace and fixtures should be kept clean and free of any type of reducible oxide deposits, and outside atmospheric leak rates should be kept as low as possible. A high atmospheric leak rate through a vacuum furnace could easily cause a thin oxide film to form on the base metal surfaces being brazed. The presence of a surface oxide film impedes the flow of the brazing filler metal, and often results in a poor brazed joint. Flux-based brazing operations can be carried out by using an induction coil heating source, or in a furnace with a reducing atmosphere.

Brazing fluxes are utilized to protect and assist in wetting of base metal surfaces. Fluxes are usually mixtures of fluorides and borates that melt below the melting temperature of the brazing filler metal. Standard brazing fluxes can be used with most Ni-/Co-base alloys. Specialized formulations may be necessary for use with certain brazing filler metals or for base metal alloys containing aluminum and titanium. There are many variables that influence the choice of the most appropriate flux, including base metal, filler metal, brazing time, and joint design. To be effective, a brazing flux must remain active throughout the brazing temperature range. Recommendations from a brazing flux supplier should be sought when considering the use of a specific flux for the first time. Flux removal after brazing is necessary, and particularly important on brazed components that will experience corrosive or high-temperature environments. Grinding or abrasive blasting may be required to remove any tenacious flux residue.

Effect of Brazing Thermal Cycles

The thermal cycles associated with brazing can have deleterious effects upon the microstructure and properties of HAYNES® and HASTELLOY® alloys. Thermal cycle exposure during brazing includes both the time at the selected brazing temperature, and the time taken to heat and cool from elevated temperature. Care should be taken to ensure that the respective brazing thermal cycle does not produce deleterious precipitation of secondary phases in the component. Thus, thermal cycles associated with the brazing operation should be controlled to minimize exposure to temperatures in the approximate range of 1000 to 1800ºF (538 to 982ºC) where most Ni-/Co-base alloys tend to precipitate secondary phases. For corrosion-resistant alloys, such secondary precipitation could strongly influence their corrosion resistance in service. Normal cooling rates from the brazing temperature, particularly in vacuum furnace brazing, are usually too slow to prevent carbide precipitation in most Ni-/Co-base alloys. Cooling rates in a vacuum environment can be increased by backfilling the furnace with argon or helium. Where brazing is performed in the solution annealing temperature range of the base metal alloy, there is the possibility for both normal and abnormal grain growth, which could be deleterious to service performance.

Table 4: Some Possible Brazing Filler Metals for HASTELLOY® and HAYNES® Alloys

Designation/Specification			Nominal Composition (wt.%)	Liquidus - Solidus	Brazing Temperature Range
AWS A5.8	ISO 17672	AMS			
BAg-1	Ag 345	4769	45Ag-15Cu-16Zn-24Cd	1125-1145°F (607-618°C)	1145-1400°F (620-760°C)
BAg-2	Ag 335	4768	35Ag-26Cu-21Zn-18Cd	1125-1295°F (607-702°C)	1295-1550°F (700-840°C)
BAg-3	Ag 351	4771	50Ag-15.5Cu-15.5Zn-16Cd-3Ni	1170-1270°F (632-688°C)	1270-1500°F (690-815°C)
BAg-4	Ag 440	----	40Ag-30Cu-28Zn-2Ni	1240-1435°F (671-779°C)	1435-1650°F (780-900°C)
BAg-8	Ag 272	----	72Ag-28Cu	1435°F (779°C)	1435-1650°F (780-900°C)
BAu-4	Au 827	4787	Au-18Ni	1740°F (949°C)	1740-1840°F (950-1005°C)
BAu-5	Au 300	4785	Au-36Ni-34Pd	2075-2130°F (1135-1166°C)	2130-2250°F (1165-1230°C)
BAu-6	Au 700	4786	Au-22Ni-8Pd	1845-1915°F (1007-1046°C)	1915-2050°F (1045-1120°C)
BCu-1	Cu 141	----	Cu-0.075P-0.02Pb	1981°F (1083°C)	2000-2100°F (1095-1150°C)
BNi-1	Ni 600	4775	Ni-14Cr-3.1B-4.5Si-4.5Fe-0.75C	1790-1900°F (977-1038°C)	1950-2200°F (1065-1205°C)
BNi-1a	Ni 610	4776	Ni-14Cr-3.1B-4.5Si-4.5Fe-0.06C	1790-1970°F (977-1077°C)	1970-2200°F (1080-1205°C)
BNi-2	Ni 620	4777	Ni-7Cr-3.1B-4.5Si-3Fe-0.06C	1780-1830°F (971-999°C)	1850-2150°F (1010-1180°C)
BNi-3	Ni 630	4778	Ni-3.1B-4.5Si-0.5Fe-0.06C	1800-1900°F (982-1038°C)	1850-2150°F (1010-1180°C)
BNi-4	Ni 631	4779	Ni-1.9B-3.5Si-1.5Fe-0.06C	1800-1950°F (982-1066°C)	1850-2150°F (1010-1180°C)
BNi-5	Ni 650	4782	Ni-19Cr-0.03B-10.1Si-0.06C	1975-2075°F (1079-1135°C)	2100-2200°F (1150-1205°C)
BNi-6	Ni 700	----	Ni-11P-0.06C	1610°F (877°C)	1700-2000°F (930-1095°C)
BNi-7	Ni 710	----	Ni-14Cr-0.02B-0.1Si-0.2Fe-0.06C-10P	1630°F (888°C)	1700-2000°F (930-1095°C)

BCo-1	Co 1	4783	Co-19Cr-17Ni-0.8B-8Si-1Fe-4W-0.4C	2050-2100°F (1120-1149°C)	2100-2250°F (1150-1230°C)

Soldering

Soldering refers to a group of joining processes that produces the coalescence of materials by heating them to the soldering temperature in the presence of a soldering filler metal having a liquidus below 840°F (450°C) and below the solidus of the base metal, i.e. without melting of the base metal. Ni/Co-base alloys can be successfully soldered, although alloys containing higher levels of chromium, aluminum, and titanium can be more difficult to solder. Many of the considerations for soldering are similar to those previously outlined for brazing of HASTELLOY® and HAYNES® alloys.

Common soldering filler metals are composed of mixtures of lead and tin. Most of the common types of filler metals can be used to solder Ni-/Co-base alloys. Soldering filler metals with a relatively high tin content provide the best wettability, such as the 60 wt. % tin-40% wt. % lead or 50 wt. % tin-50 wt. % lead compositions. If color matching is a priority, certain filler metals, such as the 95 wt. % tin-5 wt. % antimony composition, may be best. However, the soldered joint may eventually oxidize and become noticeable if there is exposure to elevated temperatures.

The soldering filler metal can be used to seal the joint, but should not be expected to provide a mechanically strong joint or carry the structural load. Mechanical strength needs to be provided for by another means of reinforcement, such as lock seaming, riveting, spot welding, or bolting. For precipitation-strengthened alloys, soldering should be performed after the alloy has gone through its age hardening heat treatment. The relatively low temperatures involved in soldering should not soften or weaken the precipitation-strengthened alloy. Any welding, brazing, or other heating treating operations should also take place before soldering. Ni-/Co-base alloys are susceptible to liquid metal embrittlement when in contact with lead and other metals with low melting points. While this will not occur at normal soldering temperatures, overheating of the soldered joint should be avoided.

Fluxes containing hydrochloric acid are typically required for soldering most Ni/Co-base alloys that contain chromium. Rosin-base fluxes are generally ineffective. Since most flux residues absorb moisture and can become highly corrosive, they should be thoroughly removed from the workpiece after soldering. Rinsing in water or aqueous alkaline solutions should be effective for removing most residues; however, in the presence of oil or grease, the material must be degreased before rinsing.

Joint designs that will be inaccessible for cleaning after soldering, such as long lap joints, should be coated with soldering filler metal prior to assembly. This is generally performed with the same filler metal alloy to be used for soldering. The workpieces may be immersed in a molten bath of the soldering filler metal or the surfaces may be coated with flux and heated to allow the soldering filler metal to coat the joint. Pre-coating may also be accomplished by tin plating.

Visual inspection is usually sufficient for evaluating the quality of a soldered joint. The soldered metal should be smooth and continuous; lumps or other visual discontinuities are indicative of insufficient heat. Holes are most likely caused by contamination or overheating, and can result in leaks. Soldered joints with leak-tight requirements should be pressure tested.