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Vacuum Brazing Furnace Technology and Applicability

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Vacuum brazing has been widely accepted where reactive metals are joined or entrapped fluxes would be unacceptable. These, however, are not the only areas where vacuum brazing can be successfully and economically employed.

The vacuum furnace is central to the brazing process; many types and sizes are available and the furnace is matched as closely as possible to the process. The elements of alloys used for vacuum brazing are susceptible to evaporation; therefore the alloy should not contain elements with high vapor pressures.

Vacuum Brazing Furnace System

A typical vacuum brazing furnace consists of a pumping system, hot zone, instrumentation and a power supply.

Pumping System

The pumping system may be a simple mechanical pump or a combination of a mechanical pump and high vacuum pump.[1] The system most commonly used is the combination of a mechanical pump with a diffusion pump. Where contamination by hydrocarbon vapors is a problem the diffusion pump may be replaced with either a cryopump or a turbo-molecular pump.

Hot Zone

The hot zone of a vacuum brazing furnace is made up of an insulation pack and heating elements. The insulation pack may be composed of metal heat shields or a fibrous material such as carbon or graphite felt. The use of felt presents some problems. The large surface area of the felt tends to adsorb gases and water vapor making low pressures difficult if not impossible to attain. Also, any oxygen which may be in the furnace will be converted to carbon monoxide which may contaminate the braze alloy or parent metal. This carbon contamination can be eliminated by using a non-carbon fiber, however, the adsorption problem remains. Both problems can be eliminated by using radiation shields in lieu of fibrous insulation. The shield pack of a typical vacuum brazing furnace comprises six shields. The first three are fabricated from .005 inch thick molybdenum; the remainder are fabricated from .005 in. thick stainless steel. In some cases the inner, or key shield, is fabricated from .010 in. or thicker molybdenum, thereby extending the life of the hot zone. The heating elements in a typical vacuum brazing furnace are fabricated from either molybdenum rod or sheet. The rod type elements have an advantage over the sheet type with respect to durability. Depending on the size of the hot zone, the power supply will be arranged to allow trimming of the power distribution to the heating elements to provide optimum temperature distribution in the hot zone.

Instrumentation

Depending on the type of material being processed in the furnace the instrumentation could be a simple temperature controller. However, the typical vacuum brazing furnace is used to process high-tech material which requires close control and recording of the process parameters. Close control of temperature is accomplished by use of microprocessor based process programmer. The latest versions of these programmers allow the use of several sets of tuning constants which enable greater control over the process. Temperature and pressure are recorded either in the analog mode using the familiar chart recorder, or digitally using a data logging system. One of the latest recording devices has the capability of both digital and analog recording, and can be switched between modes automatically.

Furnace pressure in the micron range is measured by thermocouple gauges. Pressure in the submicron range is measured either by ion gauges or by cold cathode gauges. Both thermocouple gauges and ion gauges are sensitive to the type of gas in the furnace; where this is a problem a multi-head capacitance manometer may be used.

Determining Vacuum Brazing Alloy Suitability

What makes an alloy suitable for vacuum brazing? The question is better stated as "What makes an alloy unsuitable for vacuum brazing?." The answer to this question is a low vapor pressure of each of the alloys elements. Every metal has a partial pressure of its own, surrounding vapor. At room temperature, for most metals, the amount of vapor is so small it is almost nonexistent. At brazing temperatures the amount of vapor, for metals with high vapor pressures, is substantial and can cause problems. The inclusion of high vapor pressure elements such as zinc or cadmium would make an alloy unsuitable for vacuum brazing. How does one determine if an alloy contains any high vapor pressure elements? There are many vapor tables and charts available in the literature; however thermodynamics provides a method of estimating the vapor pressure at a given temperature when the boiling point of the material is known. Using the equation[2]:

$$\ln P \cong 10.56 . \frac{(T - T_b)}{T}$$

where T is the temperature of interest in °K and T_b is the boiling point of the material in °K, the natural log of the vapor pressure can be calculated. Rearranging the above equation the vapor pressure can be found directly using:

$$P \cong e^{10.56 . \frac{(T - T_b)}{T}}$$

The vapor pressures of some common braze alloy components are shown in Fig. 1.

Properties of Some Common Vacuum Brazing Alloys

Tables I-IV contain a selection of braze alloys used for vacuum brazing. This is not meant to be an exhaustive listing, but an overview of the types of alloys that are available.

Brazing Process

Joint Design

The heart of the brazing process is the design of the braze joint. The joint should incorporate the smallest clearance that is practical because this practice makes it easier for capillary attraction to distribute the braze alloy through the braze area.

Table I Copper Silver Braze Alloys

Nominal composition percent	Liquidus °C	Solidus °C	AWS* class
Ag-60 Cu-30 Sn-10	720	600	BV Ag-18
Ag-61.5 Cu-24.0 In-14.5	705	625	BV Ag-29
Ag-72 Cu-28	780	780	BV Ag-8
Ag-71.5 Cu-28 Ni-0.5	795	754	BV Ag-8b
Ag-54 Cu-21 Pd-25	950	900	BV Ag-32
Ag-99.95 Cu- 0.05	961	861	BV Ag-0
Ag- 0.05 Cu-99.95	1083	1083	BV Cu-1x

*American Welding Society Classification

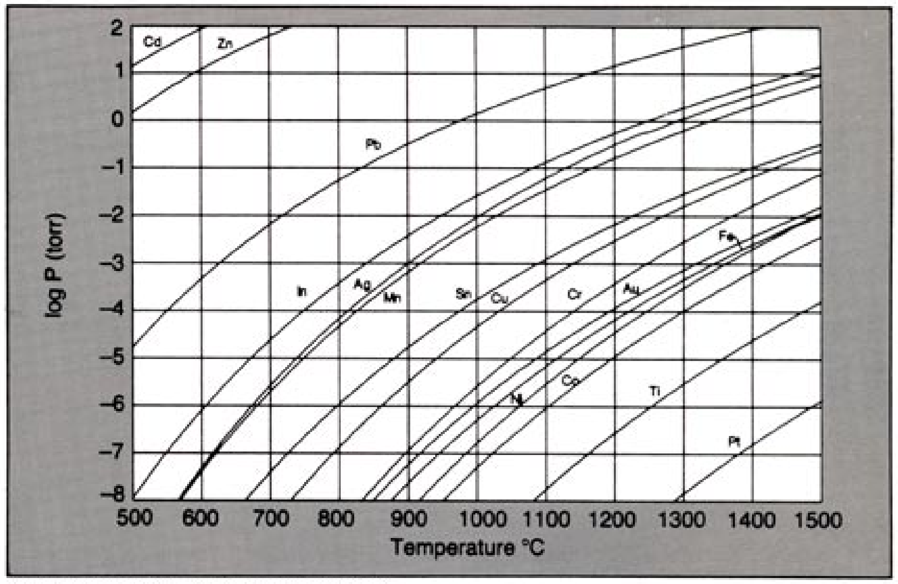

Fig. 1 Vapor pressure of brazing elements.

Also, the likelihood of formation of voids or shrinkage cavities during braze alloy solidification will be reduced. Optimum capillary action and greatest joint strength are achieved with joint clearance in the range of .001 to .003 inch. Importantly, the braze clearance may change due to thermal expansion of the base metal and this should be factored into the joint design.

Braze Joint Formation Mechanism

Capillary flow is the dominant physical principle that ensures good braze joints provided both surfaces to be joined are wetted by the molten braze alloy. Capillary flow is a function of surface tension between base metal(s), braze alloy, flux or atmosphere and the contact angle between the base metal and braze alloy. In actual practice, braze alloy flow is also influenced by dynamic considerations involving fluidity, viscosity, vapor pressure, and metallurgical reactions between the base metal and the braze alloy. Capillary flow is only part of the joint formation process, after the alloy is drawn into the joint it must wet both surfaces. Wetting is best described by example. If a solid is immersed in a liquid bath and wet-

Table II Nicrobraze*Filler Metals

NAME	Nominal composition percent	Liquidus °C	Solidus °C	AWS Class
Nicrobraze 125	Cr-14 Fe-4.5 B-3.0 C-0.7 Si-4.5 Ni-Bal	1040	970	BNi-1
Nicrobraze 50	Cr-14 P-10 C-0.08 max Ni-Bal	890	890	BNi-7
Nicrobraze 130	B-3.1 Si-4.5 C-0.06 max Ni-Bal	1040	980	BNi-3
Nicrobraze 160	Cr-11 Fe-3.5 B-2.25 C-0.5 Si-3.5 Ni-Bal	1160	970	
Nicrobraze 170	Cr-12 Fe-3.5 B-2.5 W-16.0 Si-3.5 C-0.5 Ni-Bal	1105	970	
Nicrobraze 200	Cr-7.0 W-6.0 Si-4.5 Fe-3.0 B-3.2 Ni-Bal	1040	975	
Nicrobraze 210	Cr-19 W-4 B-0.8 C-0.4 Ni-17 Si-8 Co-Bal	1150	1105	BCo-1

*Registered Trademark of Wall Colmonoy Co.

Table III Noble Metal Braze Alloys*

NAME	Nominal composition percent	Liquidus °C	Solidus °C
Platinum	Pt-100	1768	1768
Paloro	Au-92 Pd- 8	1240	1200
Palsil 10	Ag-90 Pd-10	1065	1002
WESGO Gold	Au-100	1064	1064
Palniro 7	Au-70 Pd- 8 Ni-22	1037	1005
Incuro 60	Au-60 Cu-37 In- 3	900	860
Nicusil 8	Ag-56 Cu-42 Ni- 2	893	771

*Registered Trademark of GTE WESGo

Table IV Active Metal Braze Alloys*

NAME	Nominal composition percent	Liquidus °C	Solidus °C
Ticuni	Cu-15 Ni-15 Ti-70	960	910
Ticusil	Ti- 4.5 Cu-26.7 Ag-68.8	850	830
Cocuman	Co-10.0 Cu-58.5 Mn-31.5	999	896

*Registered Trademark of GTE WESGO

ting occurs, a thin continuous film of liquid will adhere to the solid when it is removed from the liquid. Technically, for wetting to occur the force of adhesion between the solid and the liquid is greater than the cohesive force of the liquid. As applied to brazing, wetting implies that the liquid braze alloy spreads on the solid base metal instead of balling up on the surface. Furthermore, wetting depends on a slight alloying of the braze alloy with the base metal.

Cleanliness

The final factor in the production of a good braze joint is the cleanliness of the base metal and the braze alloy. Cutting oils and other types of hydrocarbon contamination can be removed by solvent cleaning methods. Surface oxides may be removed by mechanical abrasion, chemical reduction or by vacuum dissociation of the oxide. Mechanical abrasion consists of grinding, wire brushing or similar means of mechanically removing the oxide from the surface. Chemical reduction of the oxides can be accomplished using commercially available cleaning solutions. Another method of reducing the surface oxides is to maintain a partial pressure of dry hyrogen in the furnace during part of the brazing cycle. The reacion which takes place is as follows:

$$MO + H_2 \rightarrow M + H_2O$$

Where M = metal, MO = metal oxide and H = hydrogen.

This reaction is dependent on temperature and the ratio of H_2/H_2O; therefore, the thermodynamics of the particular oxide reduction should be checked prior to the use of this method. Another method of cleaning, which applies mainly to the base metal, is based on the fact that oxides are unstable at high temperature and low oxygen pressures. The base metal parts are placed in the furnace and the system is pumped down into the submicron range. The parts are then heated to a temperature at which the oxides will dissociate. This method leaves the surface extremely clean; however, application of the braze alloy and return of parts to the furnace must be in as short a time as possible or the surface will oxidize.

Evaporation of Braze Alloy Components

One potential problem with vacuum brazing is the volatilization or vaporization of braze alloy elements. As stated above, every metal has a partial pressure of its own, surrounding vapor, and that pressure is temperature dependent. The loss of material is dependent on the ability of the metal atoms to leave the surface of the metal and enter the atmosphere. In a hard vacuum (10^{-5} to 10^{-6} torr), the metal atoms find little resistance to leaving the surface. If a partial pressure of an inert gas, such as argon, is introduced into the chamber these gas atoms will interfere with the metal atoms as they attempt to leave. This interference will reduce the rate at which the metal is evaporated; however, the vapor pressure of the metal remains unchanged.

Case Studies

Semiconductor Test Fixture

The fixture shown in Figs. 2a and 2b is used to test integrated circuits by thermally cycling them. The circuits are placed on the copper blocks and the temperature of the blocks is cycled by passing hot and cold water through the system. The fixture was originally fabricated by manual torch brazing the stainless steel bellows to the copper base. This method of production had a high reject rate: the high heat needed to braze the bellows to the copper base heavily oxidized the .005 in. thick bellows causing it to leak.

The problem was solved by using a three step vacuum brazing process. In the first step all the stainless steel parts were placed in a vacuum furnace pumped to a pressure in the 10^{-5} torr range and heated to 1150°C. In this step the oxides were removed from the surface of the parts. The second step consisted of removing the parts, assembling the bellows and nipples, applying the Nicrobraze 125 and brazing the assemblies. Nicrobraze™ was used because it melts at a higher temperature than the silver braze that will be used to join the stainless steel nipple to the copper base. The brazing cycle used was as follows: Place the parts in the furnace and pump it to a pressure in the 10^{-5} torr range. Heat the parts to 1940°F (1060°C) hold for 5 min. and cool to room temperature. The final step consisted of fabricating ring preforms of Handy & Harmon Braze 720™, assembling the fixture and conducting the following braze cycle. Load the assembly in the furnace and pump into the 10^{-4} torr range. Heat the assembly to 1490°F (810°C) hold for 5 min. and cool to room temperature.

An interesting point of this job was that the fixture was 36 in. long and the effective hot zone was 24 in. long. By setting the fixture in

Fig. 2a Electronic test fixture.

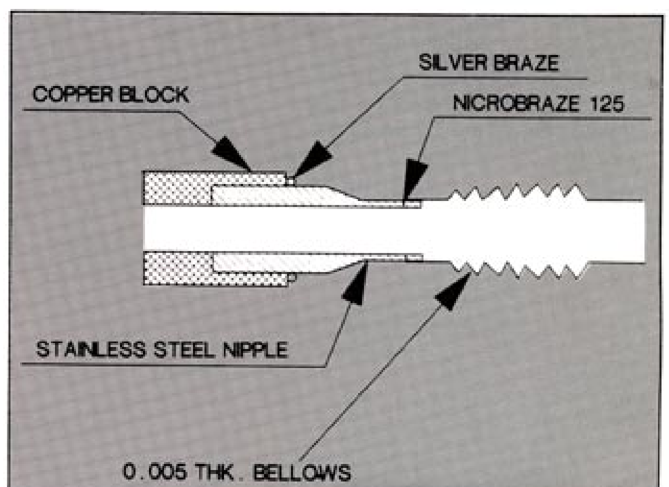

Fig. 2b Diagram of electronic test fixture assembly which is produced by vacuum furnace brazing.

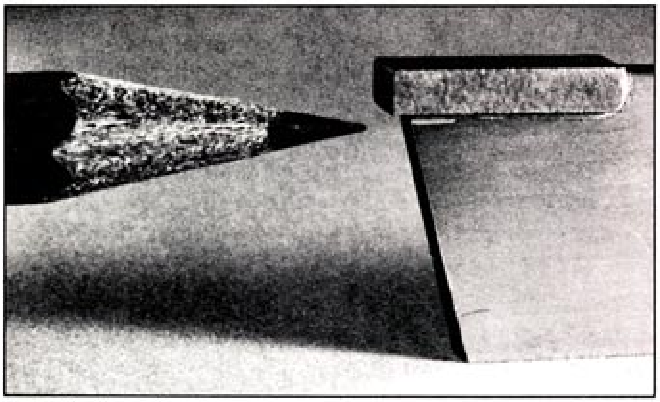

Fig. 3a Parting tool.

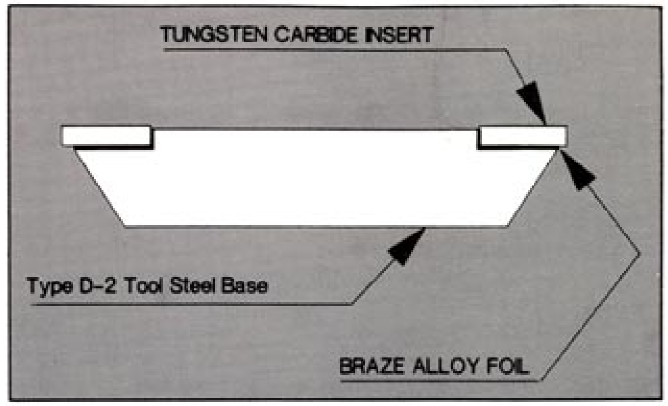

Fig. 3b Diagram of parting tool showing assembly for brazing.

the furnace diagonally and using the trimming capabilities of the power supply, the temperature distribution in the furnace was varied in such a manner that all joints brazed. Three fixtures of this type were brazed with no joint failures.

Carbide Tipped Parting Tool

The normal manufacturing method for this part was to braze the carbide tip onto the tool steel base and then heat treat the base. This added extra cost to the product. By switching to a vacuum brazing process combined with a gas quench the two steps were combined. The tool was fixtured in the vertical position for brazing and to allow good circulation of the quenching gas. The base alloy used was GTE WESGO Cocuman. This alloy was selected because of its ability to wet both the carbide insert and the tool base and because its brazing range is within the austenitizing range of the tool steel.

The brazing/heat treating procedure was as follows. The parts were fixtured in the vertical position. Then a piece of braze alloy foil was bonded to the tool steel base with a drop of nitrate lacquer. The carbide tip was then placed on the braze foil and a weight placed on top.

The temperature cycle was as follows: (1) heat the parts to 1850°F (1010°C) to both melt the braze alloy and austenitize the tool steel; (2) hold for 15 min. to allow the braze to flow and the steel to austenitize; (3) backfill the furnace with inert gas and allow the parts to cool to 1750°F (954°C) to allow the braze to solidify; (4) gas quench the parts to room temperature to harden the tool steel; (5) reheat the parts to 1100°F (593°C) to temper to a hardness of 50/55 R_c.

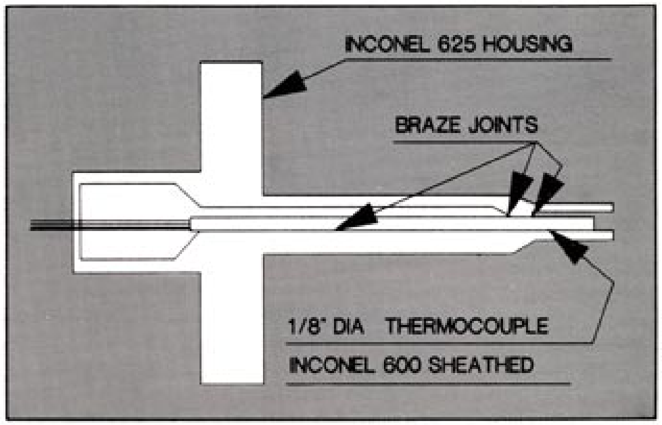

Fig. 4 Diagram of aerospace temperature sensor assembly.

Temperature Sensing Device for Aerospace Applications

This device was an experimental part which was to be used to measure temperature in the main engine of the space shuttle. Because of the severe vibration encountered during operation, the part required the braze to be free of voids and to be continuous. The problem in this job is indicated in Figs. 3a and 3b; the joint must be made in a narrow passage and a pressure seal must be made at one end. Vacuum brazing was chosen because it will produce void free joints and by vacuum cleaning the surfaces, wetting of all surfaces could be achieved.

The parts were assembled, placed in the furnace and pumped to a pressure of 10^{-5} torr. The parts were then heated to 1975°F (1080°C) and held for 1 hour. After vacuum cooling, the parts were removed and the braze alloy wire placed as indicated in Fig. 4.

The parts were placed in the furnace and heated to the brazing temperature of 1950°F (1065°C). The braze alloy specified was a gold-nickel alloy. X-ray inspection of the finished parts showed 100% bond along the thermocouple and a good seal on both sides of the wall.

Conclusion

Vacuum brazing has been widely used in areas where reactive metals are joined or where entrapped fluxes would be intolerable. It also has been applicable in areas where the joining process is complicated by factors such as part thickness or requirements of void-free joints. Vaccum brazing should not be considered panacea for curing all types of brazing problems. It is essential to adhere to good brazing practices.

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