BNP A PUBLICATION OF BUSINESS NEWS PUBLISHING

OCTOBER 1996

INDUSTRIAL HEATING

THE JOURNAL OF THERMAL TECHNOLOGY®

Literature Showcase: Vacuum Furnaces & Components ❦ Electric Heating Elements

Vacuum Brazing: A Three in One Process That Provides Efficiency

By CHARLES F. BURNS JR., V. P. of Quality Control and Brazing

and ROBERT LACOCK, Marketing Manager, Solar Atmospheres, Inc., Souderton, PA

Different metal joining processes each have advantages and applications for which they are best suited. An often overlooked capability of vacuum brazing is the simultaneous combining of three metal treatments in one process: bonding, cleaning and heat treating.

In addition, since each of the metal treatments is being done in vacuum, Fig. 1, the assembly has the unique benefits attributable to this type of thermal processing. This article will explore the advantages of vacuum brazing and the applications for which it is most suitable.

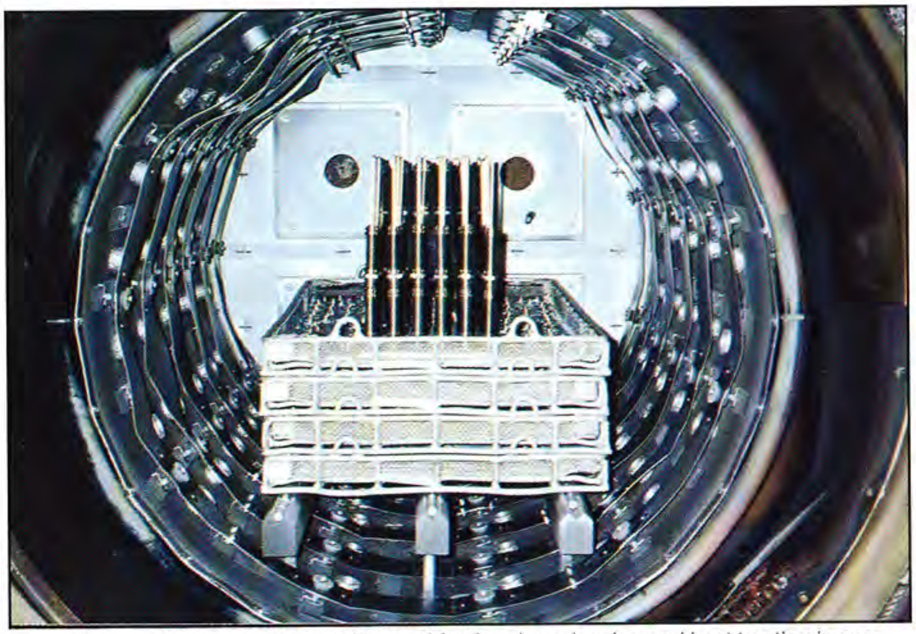

Fig. 1 Vacuum furnace can be used to combine brazing, cleaning and heat treating in one process, depending on the application, for highly efficient operation. Alloy trays hold work for production run.

Diffusion Bonding

The method of bonding metal parts by vacuum brazing is the most significant factor in determining its applicability. Vacuum brazing, most often involves a typical BNi-2 nickel braze alloy (CR 7.0, B 3.1, Si 4.5, Fe 3.0, C 0.06 max, Ni bal.) as a filler material in the gap between the components being joined. The filler material melts at a lower temperature than the components being joined and diffuses into the metal parts creating a non-corrosive bond. After brazing, the transgranular diffusion of individual elements forms a new alloy that requires a higher remelt temperature than that of the original braze alloy.

Nickel brazing alloys have extensive bonding applications including all commonly used stainless steels, tool steels, low carbon steel, and Kovar. In extremely corrosive applications, such as harsh chemical or oil environments, part assemblies can be joined with a gold/nickel alloy. Consideration needs to be given to the alloy cost factor for this application. However, in most applications the nickel alloy, with a very reasonable cost, will result in a virtually non-corrosive bond. This is illustrated by an oil lamp manufactured in Pennsylvania by the Amish (see Fig. 2). Formerly the lamp bases were made of brass and soldered around the base. The soldered oil tank seam eventually corroded. The manufacturers changed the assembly to tanks made of stainless steel components, vacuum brazed with a nickel alloy. This new process results in a leak-free, non-corrosive seal.

Most production assemblies used in manufacturing are stainless steel joined with nickel alloy; however, vacuum brazing allows a wide variety of component and alloy choices. In addition to the material already listed, vacuum brazed components can be cobalt, titanium, carbide and copper. Other brazing alloy options include: copper, silver, gold and various combinations of these metals. The brazing alloys may be in the forms of paste, powder, foil, pre-forms and even a two sided tape. Because of the alloy variety numerous non-metal materials can be joined, including ceramic to metal, diamond and other precious minerals to metal. Choosing the correct brazing requires metallurgical expertise and an understanding of the assembly application.

Metal joining is necessary for components too complex to machine. The method of forming the fillet enables vacuum brazing to have one of the most broad application capabilities for assembly configurations. Alloy is applied by a technician using needle point tips with foot controlled pneumatic pumps supplying the alloy (see Fig. 3). The final assembly can comprise an infinite variety of customized configurations.

Fig. 2 Nickel brazed lamp oil tank vacuum furnace brazed along the bottom seam and at the spout.

Fig. 3 Pneumatic, needle point, application of braze alloy to components.

Vacuum brazing also enables different component types such as tubing, capillary, machined and formed parts, to be joined into various configurations (see Fig. 4). Yet, with a pneumatic assisted application, daily production quantities can be hundreds or thousands depending on assembly configuration.

Most instrument and part assembly applications need a leak tight joint bond that vacuum brazing provides. A visual inspection can determine if the part assembly is leak tight, however, a helium mass spectrometer is used when certification of a leak tight assembly is critical. This can be done to 10^{-9} cubic centimeters/second.

A caution must be given for the bonding applications of vacuum brazing. Processing expertise is essential because of the tolerance requirements for braze joint clearance. An assembly will ideally have a joint clearance of 0.0013" to 0.0022". Vacuum brazing utilizes capillary action to draw braze alloy into the interface between two or more parts. As the braze clearance range widens, gap strength decreases drastically. Also, capillary action is reduced to nil at 0.005" gap or greater; gravity takes over and a loss of brazeability occurs. Therefore, the maximum braze clearance will influence the joint strength.

Many nickel braze alloys, which are among the preferred to bond the stainless steel alloys, contain elements that lower the melting point; these are boron, phosphorus silicon, etc. A wide gap will cause the formation of very brittle intermetallic compounds within an eutectic structure. A centerline band forms consisting of borides, silicides and phosphides which can be minimized or eliminated with the proper control over such variables as time, temperature and braze joint clearance.[1]

Sometimes, because of considerable machining, alloy, configuration and component variables, it is very difficult to immediately determine if vacuum brazing is the best method for joining. In such situation, experimentation and prototype work is necessary.

The capacity to handle a required load is jeopardized if due consideration is not given to these braze variables. Dual quality control procedures are necessary to prevent substandard joint bonding. This includes metallurgical qualifications for the alloy composition and the components to be brazed. Secondly, production technicians must be properly trained to check for dimensional accuracy. Through training and supervision, a typical plant technician can become very skilled in correct brazing alloy application. When proper procedures are followed the bonding area is not a weak link. In fact, because of the fillet diffusion bond, the strength of the joint is greater compared to alternative joining methods.

Cleaning

A critical characteristic and benefit of the vacuum brazing process is its cleaning and brightening capability. These benefits are immediately evident after the parts are removed from the furnace. Stainless and carbon steel parts are brighter and cleaner because oxides have been removed from the surfaces of brazed assemblies. The cosmetic improvement has particular importance for the instrument and medical device industries.

During the vacuum braze process the part assembly simultaneously goes through a bake out that removes oils and other contaminants from the assembly—better than chemical cleaning. This cleaning reaches machined part crevices, and the internal dimensions of tubing and short capillary tubes.

Fig. 4 Nickel brazed assembly showing the variation in components—tubing, cast and machined.

Productivity improves since no flux or other contaminants need to be removed after the vacuum braze process.

Heat Treating

The third simultaneous treatment from which vacuum brazed parts benefit is the heat treatment of the total assembly. Because the total assembly is heat treated, up to 2175°F for nickel alloy joining of stainless steel, it is metallurgically consistent. Tensile strength is consistent throughout assembly configuration. The strength of the bonded area is greater than alternative metal joining methods, and the overall assembly strength and ductility is enhanced.

In addition to enhanced assembly strength and ductility, heat treating can improve production. One of the optimum capabilities of vacuum brazing is the number of thermal treatments possible with some stainless steels and/or precipitation hardenable alloys. The potential exists to braze, harden, diffuse and temper 400 series stainless steel; braze and anneal 300 series stainless steel; braze, solution anneal and age PH grade alloys and in each case without ever removing the parts from the vacuum furnace. The nickel brazed oil tanks for the Amish lamps are work hardened during the drawing, forming stages of the stainless steel. During the brazing cycle, the work hardened assembly is simultaneously annealed.

The braze cycle, including the anneal of 300 series stainless steel involves seven steps:

(1) pump down to hard vacuum 9 x 10^{-4} or lower;

(2) ramp at 15°F/min to 1750°F ±25°F;

(3) hold at 1750°F ±25°F for fifteen minutes minimum. Work thermocouples (T/C's) indication after vacuum is below 1 x 10^{-4};

(4) End hold, ramp to 1900°-1925°F range and maintain vacuum level 9 x 10^{-4} or lower.

(5) Hold at 1900°-1925°F for fifteen minutes using work T/C's. In this temperature range the 300 series stainless steel components are brazed and annealed.

(6) Vacuum cool to 1625° ±25°F or lower using work T/C's.

(7) Nitrogen cool; extend cool for thirty minutes after work T/C's reach 150°F.

Another heat treating benefit is the flexibility of furnace production. This results from the ability to braze single or large quantities efficiently in a vacuum furnace. A commercial vacuum braze operation can process a small assembly with other jobs needing the same brazing cycle. A prominent instrument manufacturer uses vacuum brazing for JIT shipments of part assemblies. Efficient production can be achieved with continuous large batch work or the smaller jobs for JIT shipments.

A heat treater with various sized furnaces, also can schedule efficient runs of thumb nail sized or large single piece assemblies. The size of a vacuum brazed piece is only limited by the capacity of the furnace. The typical brazed part is small enough to run hundreds of brazed assemblies in a 3' diameter, 4' deep furnace with multiple layered furnace baskets (see Fig. 5).

Vacuum brazing encompasses a broad temperature range in relation to heat treating the assembly. Component materials that melt at less than 1800°F are not good candidates for vacuum brazing since this temperature at least is needed to melt the braze alloys. Contrarily, vacuum brazing can use alloys for filler that melt at 2850°F for high temperature component materials. The advantage is that heavy metals, such as tungsten, are heat treated as they are brazed with a high temperature braze alloy.

Fig. 5 Production run of assemblies in layered baskets ready for brazing and heat treatment in vacuum furnace. Control panels are shown in background.

Summary

Vacuum brazing of metal components is not just metal joining but a process that enhances the quality and value of assemblies. As a "three in one process" the diffusion bond joint is leak tight, non-corrosive and stronger than alternative joining methods. Vacuum brazing is best suited for instrument and part assemblies when component are machined or formed with close tolerances in order to achieve the extra strength of the diffusion bond. Because the alloy is applied by a technician piece by piece; machined, tube, capillary and formed components can be joined into an infinite number of configurations. Cleaning, the second simultaneous treatment, removes oxides, light oils, contaminants and results in a brighter assembly. Finally, as the assembly is brazed it also is heat treated. Metallurgically consistent assemblies result with greater tensile strength and ductility. This method of metal/material joining provides important advantages sufficient for manufacturers of instrument and part assemblies to consider as a possible metal joining alternative.

References

1. A. Sakamoto, C. Fujiwara, T. Hattori, S. Saka; 'Optimizing Processing Variables in High-Temperature Brazing with Nickel-Based Filler Metal'; March, 1989. IH