Vacuum Industries Incorporated

Special vacuum furnaces heat treat variety of alloys

TECHNICAL NOTE

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Three case histories illustrate the growing range of applications for vacuum. They include a vacuum-hydrogen process, nickel-base alloy tube annealing, and an unusual brazing operation. Kenelm W. Doak of Vacuum Industries, Inc. describes the design and operation of the vacuum furnaces.

Vacuum furnaces have gained wide acceptance for processing tool steels, stainless steels, precipitation hardening steels, and other ferrous alloys. The degree of vacuum required depends on the material heated and the process used. Many low-alloy steels can be processed in vacuum furnaces equipped solely with mechanical vacuum pumps or combination mechanical/lobe-type blower pumps. Alloys containing oxygen-sensitive elements require vacuum furnaces equipped with diffusion pumps or similar high-vacuum pumps. Such furnaces are very commonly used for processing superalloys used in jet aircraft engine applications.

The entry of vacuum furnaces into industrial heating applications has consistently progressed from initial high levels of technology and material applications to broader ranges of materials and processes. To illustrate the wide range of possibilities, three distinct furnace designs will be described.

Vacuum/hydrogen processing

A special high-performance furnace development is the high-temperature vacuum and hydrogen furnace. This design provides a valuable means of processing materials requiring both vacuum for initial outgassing and further heating in vacuum and/or hydrogen or other reducing gases to maximize physical and mechanical properties. In effect, the vacuum furnace becomes a high-temperature chemical process reactor.

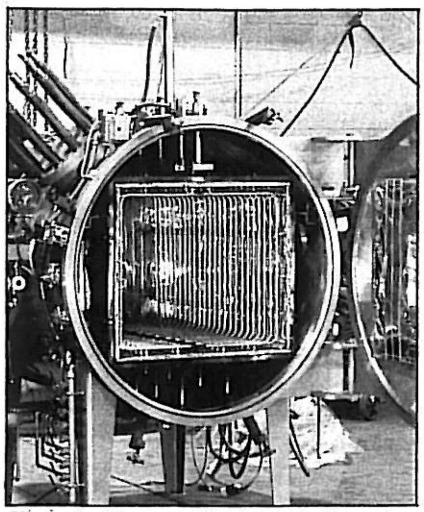

Fig. 1: Vacuum-hydrogen furnace. Tower for gas burn-off is visible at center.

The key to the successful operation of a combination vacuum/hydrogen furnace is design of interlocks so that the reducing gas can be safely introduced into the chamber for operation at temperature. A typical high-production furnace with metal resistance heat zone using tungsten heating elements and refractory metal shielding operates at temperatures up to 1650°C (3000°F), has work space 24 inches wide, 18 inches high and 36 inches long, and provides ample volume for batch production processes (**Fig. 1**). The controls are designed so that the furnace must be pumped down to vacuum and backfilled with inert gas before reducing gas or hydrogen can be introduced. The systems are designed for a flowing atmosphere of the flammable gas at a pressure above atmosphere to eliminate the possibility of air leakage into the process chamber.

Hydrogen flow is established and the exiting gas is burned off at the top of a tower above the furnace chamber. The chamber is provided with spring loaded pressure relief ports for added safety. All critical vacuum valves and ports that must be closed during vacuum operation are equipped with positive position sensors connected to the safety interlock system. When all interlocks have been properly satisfied, hydrogen processing can be conducted.

The gas inlet manifold on the side of the vacuum chamber can be branched into several feed lines leading to penetrations in the radiation shields surrounding the furnace hot zone. Injector tubes of refractory metal extend through the shields into hot zone so that the reaction gases can be directed specifically to the areas where the work is located.

The vacuum pumping system includes a 10-inch, high-vacuum pump, 245-cfm mechanical booster pump, and 150-cfm roughing pump. A 0.9-cfm mechanical holding pump is used to back the diffusion pump during periods when the roughing and booster pumps are operating for long periods. The control console provides operating, programming, and monitoring instrumentation. Microprocessor-based programmable controllers provide operating convenience and process versatility. Repeatability is insured by accurate digital programming capability.

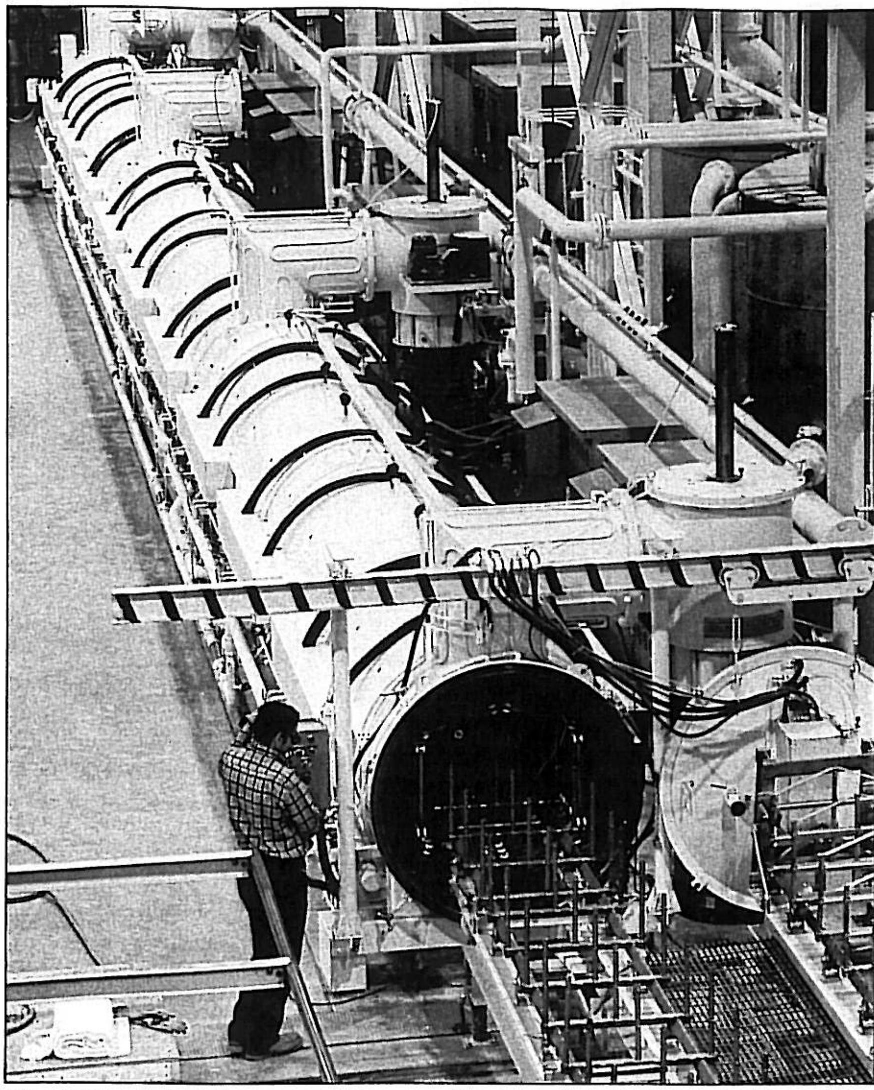

***Fig. 2:** Ninety-foot-long vacuum furnace for annealing nickel-base alloy tubing has nine separate control zones. A "traveling-front" cooling pattern is used.*

Automatic function control is standard for most furnaces of this type. Critical operations requiring safety interlock verification are displayed to insure proper operating conditions having been satisfied. Analog/digital recording instrumentation provides complete run information in easily understood form.

Typical applications for this type of furnace include decarburizing copper parts, metallizing ceramics, and brazing high reliability metal/metal and metal/ceramic components.

Nickel alloy thermal treatment

The ability of vacuum furnaces to maintain a neutral environment at elevated temperatures makes them ideal for many critical materials processing applications. One example of a large-scale industrial process involving Inconel 600 nickel-base alloy thermal treatment is a 90-foot-long tube annealing furnace (**Fig. 2**). The material problem was stress corrosion cracking. A thermal conditioning cycle offerd a solution. The neutral environment supplied the appropriate "atmosphere."

The 90-foot-long vacuum chamber contains an all-metal hot-zone assembly using a nickel-chromium ribbon heating element surrounded by alloy radiation shields. Since a typical load of nickel alloy tubing can weigh up to 15,000 pounds, materials handling is a primary consideration. As the top operating temperature of the furnace is 900°C (1650°F), an internal roller hearth can be used. The tubes are placed on load carriages resting on a roller table outside the furnace. A roll-aside cover at the front end of the furnace moves to one side so that the load carriage can be moved into the furnace by means of a power-driven mechanism.

The furnace chamber and hot zones are built in modules. The three furnace chambers each contain three hot-zone sections. A total of nine separate control zones are provided. Master/slave control is employed to achieve an overall temperature uniformity within ±3°C. This applies to steady-state load temperatures along the length of the furnace and through cross-sections. Although backfilling with argon after one hour of heating shortens the overall time required to attain steady-state conditions, this approach is not practical because the hot gas degasses otherwise cool sections of the furnace, with resultant load discoloration (**Fig. 3**, p. 24).

High vacuum is achieved with a series of 20-inch, high-vacuum diffusion pumps backed by 600-cfm mechanical boosters with 300-cfm rotary piston pumps exhausting to atmosphere. To maximize oil-free conditions in the furnace chamber, each diffusion pump is equipped with a −40°F refrigerated baffle.

Automatic programming controls handle the complete operating cycle from start to finish, with strip charts to record and monitor data.

After the thermal conditioning cycle, which lasts several hours, the load is cooled prior to removal from the furnace. Mechanical and physical characteristics of the material are not dependent on specific cooling rates. The practical aim is to minimize overall cycle time. The inert gas cooling system finally selected for the furnace takes advantage of both the load characteristics and the vacuum chamber characteristics.

Because the loads consist of hollow tubes up to 90 feet long, it is possible to introduce gas into the tubes from their ends to gain the added advantage of gas cooling on their inside surfaces. A main blower is positioned at the far end of the furnace to direct high-velocity inert gas toward the open ends of tubing. The gas moves along the tubing over the entire length of the furnace and exits at the loading end.

A secondary blower aids in returning the gas to the main blower in the space between the outside of the furnace shield enclosure and the water-cooled furnace chamber. The water-cooled furnace chamber serves as the only heat exchanger, removing the heat absorbed from the tubes by the gas before it is recirculated. The extremely large surface area of the inside of the vacuum chamber provides ample heat exchanger capacity.

The load of tubing cools progressively from the rear end of the furnace toward the front loading end.

Vacuum

Temperature profiles along the work verified the traveling-front cooling mode. Typically, a 15,000-pound load of nickel alloy tubing cools from 1200°F to 550°F within 240 minutes. Tube straightness after cooling is maintained well within allowable tolerances by virtue of the traveling-front cooling pattern, preferred to the radial flow cooling patterns that have been observed to cause camber with high-aspect-ratio loads. Cold-wall furnaces of this design, operating successfully in the United States, Japan, and Sweden, are examples of advanced vacuum and thermal technology helping to solve practical processing problems for high-performance materials.

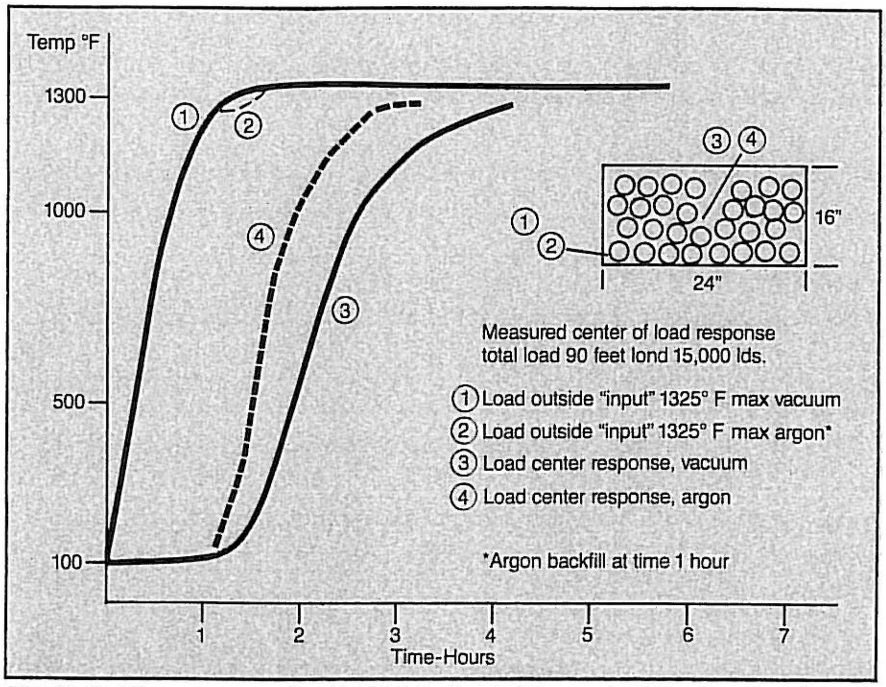

Fig. 3: Heating response for 15,000-lb. load of Inconel 600 tubes cooled with argon gas.

Special vacuum brazing

Many vacuum furnaces are used for multi-purpose processing including heat treating, thermal conditioning, and brazing. For specialized joining operations, vacuum furnaces are often dedicated to specific brazing processes. Furnaces used for brazing require fast response, good temperature uniformity, and controls that can be programmed for automatic and repeated operation. Temperature monitoring is required. In many cases, operators still prefer to visually inspect work during brazing operations to ensure satisfactory results.

Vacuum brazing has proven to be an effective means to produce single-layer, super-abrasive tools for specialized applications. To make a typical tool, diamond particles are applied to the desired surfaces prior to vacuum processing. The assembled parts are placed in a vacuum furnace and are processed in cycles suitable for the tool and the abrasive components used. Cooling from processing temperature is conducted in inert gas to shorten the overall cycle time.

Vacuum brazing ensures excellent bond, absence of gaseous contaminants in the braze material, and bright surfaces on the remainder of the tooling. For best results, vacuum brazing furnaces should be equipped with rapid-response metal heating elements that radiate heat to the work from top, bottom and sides (**Fig. 4.**). Partial-pressure controls can keep inert gas pressures at levels suitable for the brazing alloys tempered. In many cases, high vacuum is used for initial degassing.

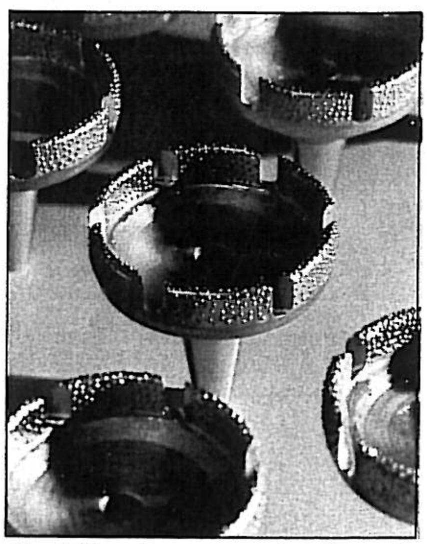

Fig. 4: Monolayer superabrasive tools vacuum-brazed in fast-response furnace.

The diamond tools illustrated have been processed in a cold-wall vacuum furnace with a 12-inch-wide x 12-inch-high x 24-inch-long hot zone capable of 2400°F in a vacuum on the order of 10^{-5} torr. (These tools are manufactured by the Permattach Diamond Tool Corp., Milford. N.H.) Vacuum-brazed tools are believed to be superior to tools processed in ordinary hydrogen atmosphere furnaces. As with the latter, dimensional tolerances and bright surfaces are maintained.

A highly specialized use for vacuum brazing furnaces is for production of medical implants. Tantalum alloy envelopes for pacemaker-type implants are processed in very high vacuum using all-metal-construction hot zones. Vacuum brazing is also used for precise operations such as joining stainless steel bellows to copper blocks for specialized heat sink components. Although vacuum furnaces of all shapes and sizes are being used for vacuum brazing, practical limitations of heat transfer in vacuum normally dictate small batch sizes for even heating and uniform results.

Acknowledgements

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