Continuous-Belt Furnace for Brazing, MIM and High-Temperature Sintering

Fig. 4. Centorr Vacuum Industries' belt furnace for the processing of advanced metals and ceramics

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Processing metals and ceramics can require very special firing conditions and operating environments in order to achieve optimal physical properties.

While conventional vacuum, atmosphere batch and continuous-belt or pusher furnace designs work well for a majority of applications, there are some unique materials (or processes) that could benefit from an ultra-clean, oxygen-free environment and a fast ramping speed with minimal soaking times.

Although vacuum and atmosphere batch furnaces are commonly used in industry, cycle times can be long, and there can be variances present throughout the load, especially when processing a large quantity of small parts in a large furnace chamber.

Conventional belt furnaces utilize Inconel mesh belts, have refractory ceramic (brick or fiber) insulation and can process loads up to several pounds per square foot of belt area. They are typically rated for maximum continuous use at temperatures to 1150°C (2100°F) or up to 1288°C (2350°F) for units with ceramic belts. While large belt and pusher furnaces are ideally suited for high throughput – such as applications found in the powdered-metal market – they are not as economical for lower-volume, shorter furnace runs of small parts under 0.25-0.5 inch (6-12 mm) in size that need to be run in ultra-clean environments.

These conventional belt furnaces require expensive nickel-alloy or ceramic muffles inside the hot zone to help control, protect and direct the reducing gas away from the insulation and heating elements, and maintain the desired furnace atmosphere. They must also be cycled with dummy loads during periods of non-use to prevent overheating of the main chamber. For improved cleanliness, some designs also include a "humpback" feature that lifts the belt and load into a higher area of the hot zone where cleaner, lower-dew-point hydrogen gas is present.

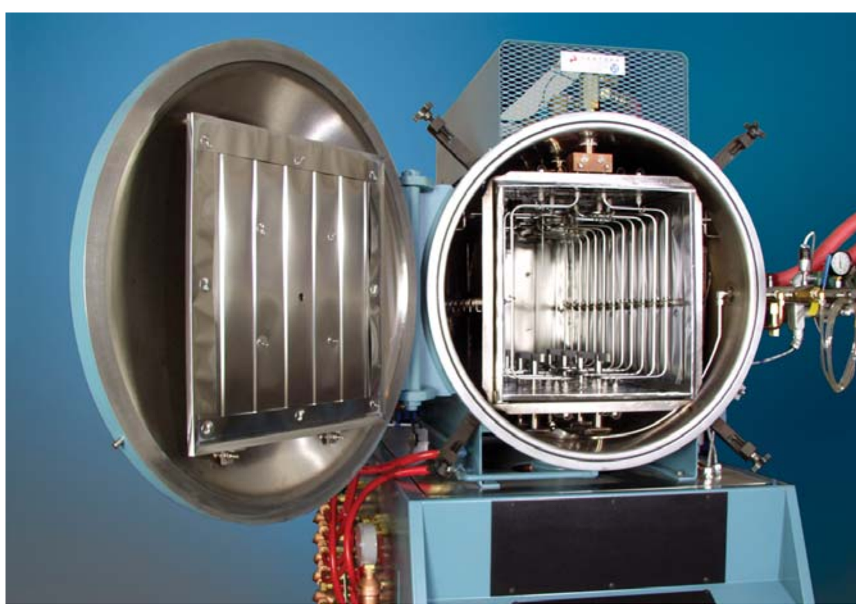

Fig. 1. Conventional vacuum-furnace hot zone

High-Temperature Continuous-Belt Furnace

To address the above concerns and accommodate these niche "small-volume, fast-throughput" applications, a new style of furnace design was conceived. It was born of the benefits of vacuum batch furnaces with the processing speed and process uniformity found in continuous designs. This novel high-temperature continuous-belt furnace is shown in Fig. 2.

While this unique belt-furnace design was originally introduced in the early 1990s, its popularity has begun to rise in the past five years as a number of new applications have opened up for its use. The furnace is built similar to vacuum-furnace construction with a water-cooled stainless steel chamber and an interior hot zone designed using refractory metals for the heating elements and shielding (such as molybdenum or tungsten) or rigid graphite insulation and graphite elements for ceramics applications.

These unique continuous furnaces are rated for maximum temperatures of 2000°C (3630°F) in either inert or process hydrogen gas with a refractory-metal hot zone or up to 2800°C (5075°F) in inert gas when using graphite hot zones. To provide fast heat-up and cooldown, a double-wall, water-jacketed entrance and cooling tunnels are located on the ends of the chamber.

For material transport, the furnace is fitted with a range of belt materials depending on use temperature and load weights. This includes a proprietary patented molybdenum or tungsten mesh-belt design rated to 1550°C (2822°F) or 2000°C (3630°F). For higher-load applications, silicon carbide link belts are used to 1800°C (3270°F), and flexible graphite cloth is the belt material of choice for temperatures over 2200°C (3990°F). The furnaces are available in a range of sizes and throughputs with a nominal belt width of between 2 and 8 inches (50-200 mm).

The throughput and process repeatability have made this furnace a successful tool for dependable production in applications such as precision brazing, metal injection molding (MIM) and high-temperature sintering of refractory metals and ceramics, as well as metallization and ceramic-to-metal joining of components. Recent installations to date have centered around applications in hydrogen brazing, high-temperature sintering, micro-MIM parts and sintered silicon nitride components. Three application case histories are presented here.

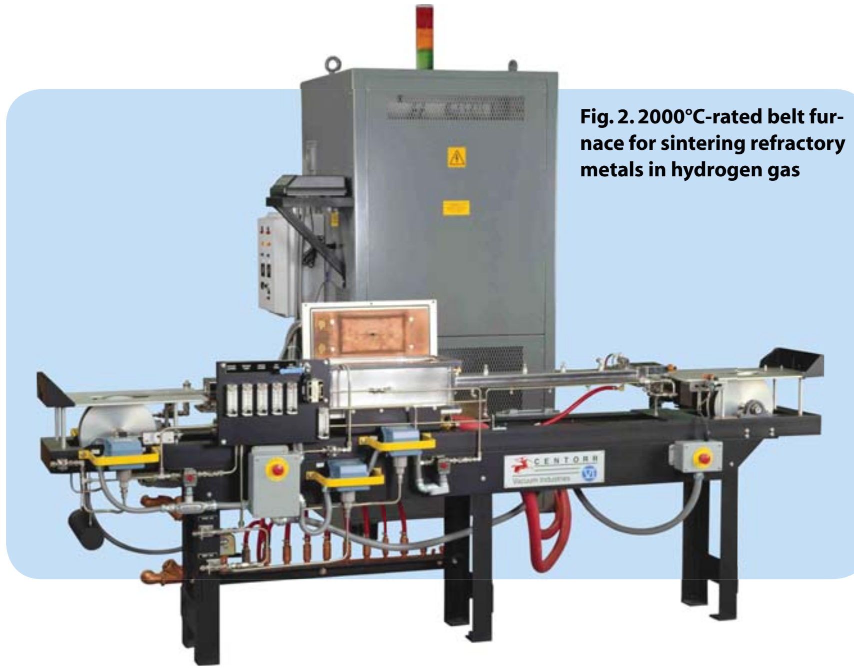

Fig. 2. 2000°C-rated belt furnace for sintering refractory metals in hydrogen gas

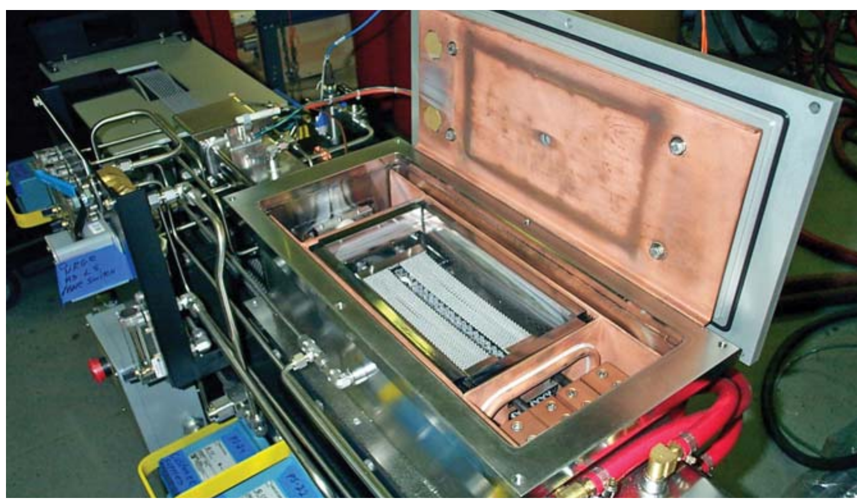

Fig. 3. Refractory-metal belt-furnace hot zones

Brazing

Conventional brazing encompasses a wide variety of techniques and materials, and it can be performed in a variety of furnace equipment. For some specialized braze materials, however, either vacuum batch processing or hydrogen belt or pusher furnaces are used.

Medical Equipment

One such niche process would be for the precision brazing of very small, lightweight parts such as those found in the medical industry. In this case, the secret to excellent brazing is summarized by the mantra of "get to temperature quickly, stay there a short period of time and get down in temperature quickly." The primary reason for this sentiment is the desire to minimize high-temperature reactions between the braze filler metal and base metal, which can occur if the two materials are in contact at temperatures above the liquidus point for long periods of time. A second corollary reason is that the shorter the overall cycle time, less time

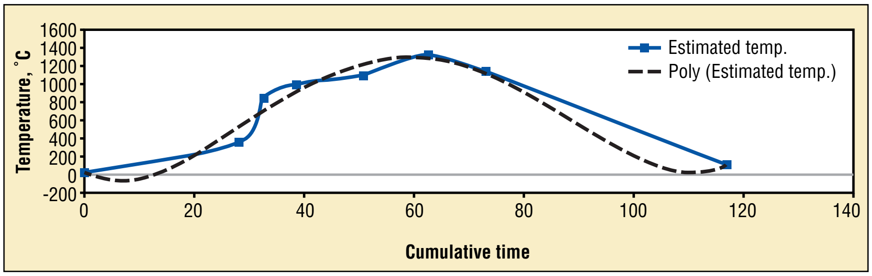

Fig. 5. Belt-furnace time-temperature modeling curve for a MIM process run at 1 inch/minute (25 mm/min), yielding fully sintered parts in 120-minute cycle time

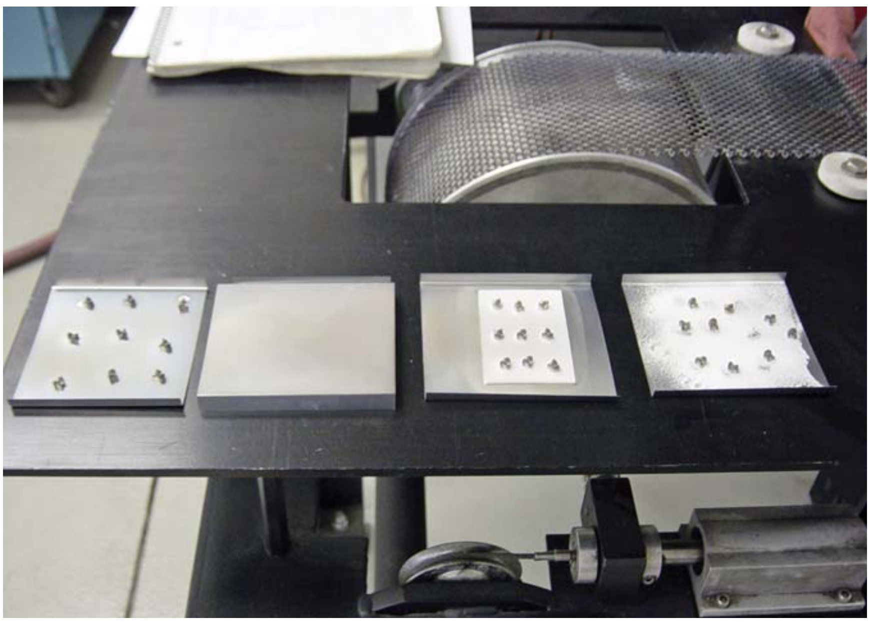

Fig. 6. Trays of small hinges on varied ceramic setter materials including sapphire, ceramic paper and alumina powder

is available for contamination of the base metal to occur. This can result in brazing defects such as poor adhesion between base metal and filler metal and insufficient bonding properties.

In order to achieve this goal, a very clean "vacuum-like" atmosphere is desired to ensure little to no oxidation of the base metal. This means conventional belt or pusher furnaces could not be used because these designs cannot offer the fast cycle times and level of cleanliness and low dew point required for some braze processes, such as those involving active metal or Ti-Cu-Ag/Ti-Cu-Ni formulations.

Customer 1 had a difficult brazing request for a small medical part that used a tiny amount of braze at temperatures under 1100°C (2012°F). After testing in various vacuum batch furnaces and batch hydrogen units, it was decided to try the parts in the belt furnace using hydrogen process gas to maintain a clean, oxygen-free environment. While the parts processed in the batch cycles were acceptable, there were braze blush variances throughout the load due to the different thermal conditions each part was subjected to. Also, each cycle took on the order of 3-4 hours whether the unit had a full load or not.

After completing two days of test runs at varying belt speeds and zone temperatures, the customer achieved parts that exited the 6-inch-wide by 36-inch-long hydrogen belt with excellent surface finish, a bright shiny exterior and excellent braze joints. Furnace speeds of 3 inches/minute (75 mm/min) were used during development, which provided a door-to-door time of just under 40 minutes.

For budget reasons and total capacity requirements, this customer opted for a 4-inch-wide belt furnace with an 8-inch-long hot zone. A belt speed of approximately 0.5 inch/minute (13 mm/min) would have been appropriate to provide a similar time at temperature inside the furnace hot zone, compared with the lab testing in the 36-inch-long unit. This customer made their initial runs at the same 3 inches/minutes (75 mm/min) speeds, however, and found that the parts came out every bit as shiny and clean as the lab testing done in the longer-belt-furnace design.

While not true for all applications, because the mass of these parts was so small, this customer found that their parts would almost instantaneously heat up inside the hot zone, which is bathed by the low-dew-point H_2 gas. Due to the small amount of braze material present, this results in contamination-free joining in a matter of seconds. This application simulated the speeds of batch induction brazing, except for the ability to continuously and safely maintain the clean hydrogen-gas environment.

The only operational issues on-site have been related to environmental conditions on the shop floor. Due to the small size of the furnace openings, if the entrance or exit tunnels are close to a loading dock or large window, the gas curtains and process-gas chimneys can have their flow patterns disturbed, resulting in frequent flow adjustments to the gas panel.

It was also determined that the furnace preferred to be run with a full load of workboats to get consistent gas-flow dynamics. Otherwise, the process gas that is introduced into the main chamber and entrance/exit tunnels will preferentially exit out the furnace end with the smallest blockage. Happily, the customer has noticed that the water-cooled shell of the furnace results in almost no heat radiation to the surrounding plant environment (as opposed to the significant heat generated from conventional brick-lined furnaces), and the furnace operation has not impacted facility heating or air-conditioning utilities.

Metal Injection Molding (Micro-MIM)

Client 2 was looking to manufacture large quantities of a relatively small part with the flexibility to start and stop runs several times per week. These parts were made of stainless grades including 17-4PH or 316L, and applications included orthodontic braces and brackets, cellphone cam-hinge pieces and miscellaneous small parts under 5 grams each.

Unlike the previous applications, this one added the complexity of removing up to 1-3 weight % of a difficult polymer-based binder system commonly used in metal injection-molded parts during a low-temperature binder burnout step. In this case, the belt furnace's hydrogen flow-through gas provided an excellent vehicle to break down the binder's hydrocarbon chains so that off-gassing could be safely removed from the parts and reduced to gaseous form with little solid binder residue left in the entrance tunnel. In certain applications, a gas moisturizing system can be added for processes requiring higher hydrogen-gas dew points (typically from -20°C/-4°F to over 20°C/68°F), such as those used in metallizing applications or instances where moisture assists in the binder removal phase.

Here again, the small cross section and fast throughput of the belt furnace were advantageous in providing a thorough and uniform debinding environment, which is considered a bottleneck in batch sintering applications where larger loads must be debound slowly with several holds at intermittent temperatures.

By keeping the load weights light and the furnace cross section small, the parts are intimately and quickly debound before entering the sintering section. By using a specially designed gas labyrinth curtain at the entrance and exit zones, the customer is able to maintain the clean environment inside the furnace even at the tunnel ends and ensure that the hydrogen process gas is directed up the burnoff chimneys located at both ends.

Final sintering of the parts took place in the main furnace chamber, and the three zones of control were individually adjusted to get the desired heat-up, soak time and cooldown profile. This resulted in theoretical densities of 97% for the 316L components in cycle times of 120 minutes.

Future work in the MIM field is being performed to determine the effect of cycle times on carbon control and to investigate blended-gas atmospheres in an effort to reduce operating costs.

Fig. 7. Graphite hot zone and SiC belt in ceramic belt furnace

Ceramic Processing

In 1993, Centorr Vacuum Industries cooperated in a study by Dale Wittmer, professor at Southern Illinois University, to develop a cost-effective means of sintering selected Si_3N_4 compositions in large volumes required by the automotive industry. While these parts could be reliably produced in a batch process, the major barrier to extensive use of Si_3N_4 components was cost.

The primary areas of research had to do with evaluating low-cost raw-material powders and the sintering process. Previously, Wittmer and Miller showed that it was feasible to sinter large Si_3N_4 disks of 100-150 grams to full density in a continuous-belt furnace in flowing nitrogen gas. A comparison was made between continuous sintering in a commercial belt furnace and sintering in a batch furnace for similar times and temperatures.[1] For the Si_3N_4 sintered in the belt furnace, the average four-point flexural strength was found to be 35% higher with a fracture toughness over 22% greater.

Remarkably, the overall cycle times for the continuous process were in the range of 3.5-4.5 hours compared with 18- to 24-hour cycles in batch sintering furnaces. This translated to a reduction in time-at-sintering temperature of 30-60 minutes for continuous compared with more than 3 hours in the batch process. It was determined that this reduced time in the presence of flowing nitrogen gas was one of the main reasons the continuous furnace provided enhanced material physical properties. Another explanation why the continuous furnace made parts with improved properties when compared with pressureless sintering furnaces or even overpressure furnaces is that the belt furnace provides very fast uniform heating and cooling (as the effective hot zone is essentially a 4 inch by 4 inch square), which positively affects the structure of the material.

Depending on formulation, the parts could be processed in graphite, BN or ALN workboxes with or without the use of packing powders. Early work was done in a tungsten hot zone, but the SiO vapor attack that dissociated off the load was degrading to the refractory metal. Later designs at SIU used an all-graphite hot zone with rigid graphite-board insulation and graphite resistance-heating elements.

And while SiC formation was a concern with the graphite hot zone, the new belt-furnace hot zone lasts significantly longer than what is achieved in graphite batch furnaces or tungsten refractory-metal designs. Fears about a graphite hot zone contributing to a carbon reaction layer have also been alleviated because there was no difference in the material properties produced in tungsten versus graphite hot zones.

In recent years, this work has transferred over to other ceramic formulations traditionally processed in batch sintering furnaces. It has led to more work in oxide sintering with sapphire formulations for applications in wafer annealing and LED processing and polycrystalline alumina for metal-halide lighting. Benefits of improved densification, minimized weight loss due to dissociation and preferred crystallinity are possible with this unique belt-furnace design.

Summary

Centorr Vacuum Industries has specialized in the development, engineering, design and manufacturing of vacuum and controlled-atmosphere furnaces since 1954 and has been expanding its niche areas from both temperature and material-handling perspectives. Their low-mass, fast-throughput belt-furnace design operates in ultra-clean environments of inert or process hydrogen gas that are used over a wide temperature range from 1000°C (1832°F) up to 2800°C (5072°F).

While this continuous furnace design is not suitable for all applications, it can provide the combined benefits of fast cycle times in an oxygen-free atmosphere, which are only found with this unique design, if considered for the right process. **IH**

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