HEAT TREATING POWDER INJECTION MOLDED & ADDITIVE MANUFACTURED PARTS

CARBOLITE GERO offers suitable furnaces for the various process steps in powder injection molding and additive manufacturing of metal and ceramic parts, such as thermal or catalytic debinding, drying of parts e.g. after solvent debinding, stress relieving, as well as sintering under protective gas, hydrogen or vacuum.

Additive Manufacturing (AM) involving metals can be divided into direct and indirect processes. CARBOLITE GERO has purposely designed their product ranges to the highest specifications; with the GPCMA for direct, and the HTK for indirect 3D Additive Manufacturing and Powder Injection Molding (PIM) processes. These are just two products from the comprehensive additive manufacturing portfolio offered by CARBOLITE GERO.

Stress relieving in direct AM processes

In the direct process, the starting powder is selectively melted and solidified on top of each other so that the complex three-dimensional part is directly produced layer by layer.

When metal powders are melted using a laser (selective laser melting SLM – standard designation: Laser Powder Bed Fusion L-PBF), subsequent heat treatment of manufactured parts is required.

The SLM process is digitally driven, direct from 3D CAD data. For each slice of CAD data a thin even layer of fine sieved metal powder (titanium alloy Ti6Al4V, cobalt chromium, stainless steel, nickel alloys Inconel 625 and Inconel 718 and aluminium alloy AlSi10Mg) is deposited on the build plate, before the selected areas of the powder are precisely melted by the laser. This precision process is repeated building up, layer by layer, until the finished part is complete.

SLM can be used for very small parts and features. It can reproduce geometries that would otherwise be impossible to machine such as enclosed spaces. Layers can be as thin as 20 microns and tolerances on small features can be as small as ±50 microns.

At present build rates for parts using a SLM process are relative slow. Costs are also high as raw metallic powders must be produced using a ball-mill/grinder and then sieved and tested prior to usage. Current SLM machinery requires a substantial investment.

However, if the required part has dimensions up to 250 mm x 250 mm x 350 mm the process could well be perfect for organisations who require rapid prototyping or small quantities of complex or ‘impossible’ parts that can subsequently be machine drilled, slotted, milled, reamed, powder coated, painted, polished or anodised.

Fig. 1: GPCMA Modified Atmosphere Furnaces for stress relieving of parts manufactured by SLM at temperatures up to 1200 °C with a possible oxygen content < 30 ppm.

Parts manufactured using the direct additive manufacturing method SLM exhibit high residual stresses due to the locally concentrated input of high energy and the formation of a high temperature gradient below the melt pool.

The reduction of the residual stresses requires subsequent heat treatment with precise temperature uniformity. For this purpose, the component is kept at a certain temperature for a specified period of time. The heat treatment stage must be precisely controlled in order to set the mechanical parameters of the selected metal alloy in a targeted manner by relieving the residual stresses effectively.

In addition, the heat treatment is carried out in an inert atmosphere to ensure the sintered part is not contaminated by oxygen molecules which can alter the chemical and physical properties of the final part.

With the **General Purpose Chamber Modified Atmosphere (GPCMA),** CARBOLITE GERO offers a product for stress relieving of additive manufactured components, which minimizes the daily operating costs, avoids unwanted oxidation and ensures "best in class" temperature uniformity.

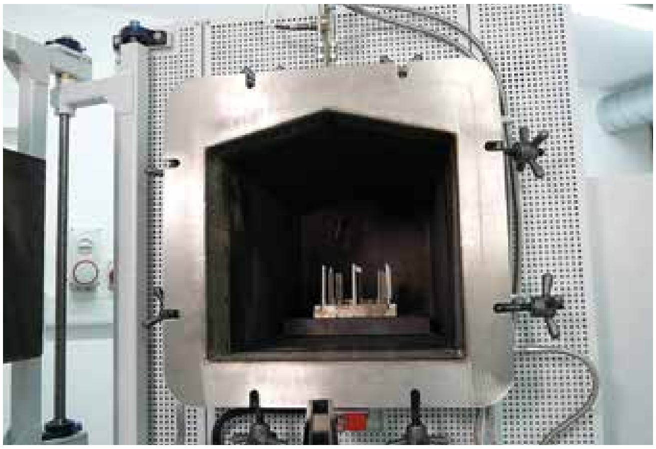

Fig. 2: View into metallic GPCMA/174 retort with additive manufactured sample for stress relieving contained therein.

Various sizes are available **(GPCMA/37, GPCMA/56, GPCMA/117, GPCMA/174, GPCMA/208 & GPCMA/245)** with capacities for between 1 and 4 build plates to fully utilize the chamber volume even with small sample sizes. This range of furnaces can be optionally specified for compliance to AMS2750E Nadcap class 1 for aerospace applications when used with an Inconel or Haynes 230 retort.

The heat treatment stage occurs in an inert (typically Nitrogen and Argon [for Titanium]) atmosphere. Oxygen levels can be reduced to 30 ppm depending on the application.

The GPCMA range has under hearth heating combined with heat from the top and sides to improve temperature uniformity inside the retort where temperature thermocouples are located. The positioning of the Cascade Controls inside the retort enables faster heating times which can substantially reduce customer cycle times when used in conjunction with optional forced cooling.

To further shorten cycle times, the GPCMA/174 furnace has a temperature interlocked double-pivot door facilitating quick, safe and easy access for loading / unloading with a water-cooled silicon rubber door seal which maintains, a modified atmosphere inside the chamber throughout the entire heat treatment process.

Fig. 3: HTK Metallic Chamber Furnace for debinding and sintering of injection molded and additive manufactured parts up to 1450 °C.

Backbone debinding and sintering in PIM and indirect AM processes

In the indirect additive manufacturing process and the powder injection molding process, which is suitable for metals and ceramics, the starting powder is mixed with a binder. The binder, which is still present after the shaping of the Green Part, will be removed in a next step thermally, catalytically or with solvents, which leads to a shrinkage of the part. The resulting Brown Part can then be sintered, giving the part its final shape and properties.

First, the main binder will be removed, e.g. thermally. After this process step, the powder is only held together by a backbone binder, which makes the part very sensitive. In a further step, the backbone binder is then thermally removed and the part sintered directly in the same furnace. The debinding steps require the removal of the gaseous waste products and a precise temperature distribution in order to specifically adapt the material properties of the sintered part. Debinding can take place under vacuum, air or inert gas. The letter ones are often used as carrier gases to improve the gas flow, to "sweep away" the binder offgassing and to shorten the debinding time. The sintering step requires furnaces with specific atmospheres, which are available in the CARBOLITE GERO product portfolio. To avoid oxidation of most metals and non-oxide ceramics, the sintering step is performed under inert gas (Ar or N_2), or reducing gas (H_2 for stainless steel); for high-purity applications, such as titanium sintering, even operation under high vacuum is required. Oxide or nitride-based ceramics such as alumina, zirconia and aluminum nitride can be sintered in air.

CARBOLITE GERO's HTK is perfectly suited for backbone debinding and sintering of additive manufactured or powder injection molded parts. The high temperature uniformity allows precise debinding and sintering all over the total chamber volume. The possibility to work under inert or reactive gases, high vacuum or even ultra-high vacuum enables sintering of very sensitive materials.

The rectangular design with a front door allows for easy loading and unloading of the fragile parts that only contain the backbone binder – main binder was removed before. The HTK range is available in four different sizes, 8 litres, 25 litres, 80 litres and 200 litres.

The metallic furnaces constructed of tungsten (HTK W) or molybdenum (HTK MO) permit the greatest possible purity of inert atmosphere and final vacuum level in the high vacuum region (5 x 10^{-6} mbar). Even an ultra-high vacuum can be configured. Common gases that are typically used include: Nitrogen, Argon (titanium), Hydrogen (stainless steel) or mixtures.

The heating elements are made from the same metallic material as the insulation. The heating insulation is constructed of several radiation shields made from tungsten or molybdenum with respect to the furnace type selected. With a retort the gas flow can be guided and the temperature uniformity is improved. The maximum temperature for the HTK W is 2200 °C and 1600 °C with the HTK MO.

The gaseous waste products generated during debinding are passed through a heated gas outlet and burnt in the afterburner. CARBOLITE GERO enables contamination-free sintering of highly sensitive materials through a switchable gas flow. This can be seen in Fig. 4.

During debinding, the gas flows from the top through the right inlet behind the retort. Since this is not fully sealed and the pressure outside is slightly higher than inside the retort, the gas flows into the retort. By flowing through the retort, the carrier gas takes the gaseous binder with it into the gas outlet at the bottom of the retort. Those gases are then directed through the heated outlet to the afterburner.

After the debinding step, the gas flow can be changed to provide the purest retort atmosphere. The gas now flows through the upper left inlet directly into the retort and from there to the outside of the retort, where it passes through the lower right gas outlet into the afterburner. Due to the lack of gaseous binder parts, the outlet no longer needs to be heated.

This changed gas flow prevents binder residues that might be outside the retort from getting back onto the samples during sintering resulting into clean samples.

Inside the chamber, heating elements are positioned at the bottom, left, right, and top sides of the furnace chamber allowing for improved temperature uniformity. For larger volumes, the back wall and front are equipped with heating elements to maintain excellent temperature uniformity. The HTK furnaces are surrounded by a water cooled vessel; thus classifying, the HTK systems as a cold wall furnace. The cooling water is guided through the double walled vessel.

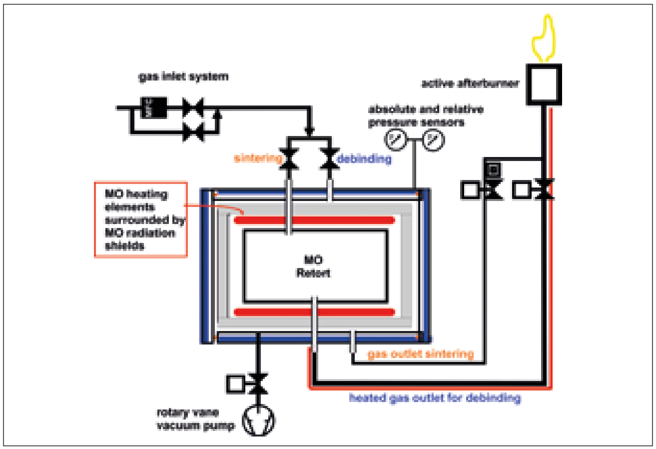

Fig. 4: Gas guidance during debinding or sintering through the retort.

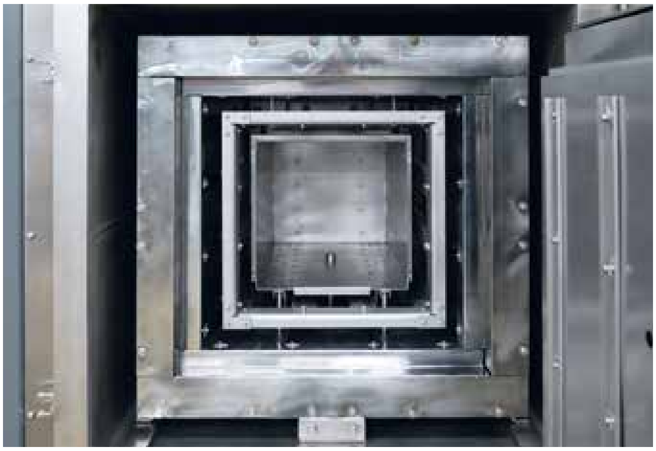

Fig. 5: Mo retort of the HTK for highest possible purity of atmosphere and vacuum level.

CARBOLITE GERO – HEAT TREATMENT

CARBOLITE GERO is a leading manufacturer of high temperature furnaces and ovens from 30 °C to 3000 °C with a focus on vacuum and special atmosphere technology. With more than 80 years of experience in thermal engineering our products are used in research laboratories, pilot plants and manufacturing sites worldwide.

- **Ovens**
- **Chamber Furnaces**
- **Tube Furnaces**
- **Vacuum Furnaces**
- **Special Applications**
- **Custom Designed**

Find out more at **www.carbolite-gero.com**

Conclusion

With the GPCMA, CARBOLITE GERO offers a product for stress relieving of additive manufactured parts, which minimizes the daily operating costs for our customers, avoids unwanted oxidation and ensures "best in class" temperature uniformity. Most importantly, production cycle times are minimized thanks to heating on all sides, optional forced cooling and simple loading & unloading through the unique water-cooled, silicon sealed double-pivot door.

CARBOLITE GERO's HTK is perfectly suited for backbone debinding and sintering of powder injection molded or additive manufactured parts. The high temperature uniformity allows precise debinding and sintering all over the total chamber volume. The greatest possible purity of inert atmospheres, final vacuum level in the high vacuum region and even the possibility of ultra-high vacuum enables sintering of very sensitive materials such as titanium.

On request, CARBOLITE GERO offers customer trials to validate a heat treatment process for their additive manufactured parts.

Model	Dimensions: Internal retort H x W x D [mm]
GPCMA/37	205 x 337 x 538
GPCMA/56	229 x 400x 610
GPCMA/117	279 x 500 x 840
GPCMA/174	428 x 500 x 815
GPCMA/208	428 x 500 x 970
GPCMA/245	650 x 700 x 1050
HTK 8	190 x 170 x 200
HTK 25	250 x 250 x 400
HTK 80	400 x 400 x 500

CARBOLITE GERO SOLUTIONS FOR ADDITIVE MANUFACTURING & POWDER INJECTION MOLDING

GPCMA Modified Atmosphere Furnace for Additive Manufacturing

- **Stress relieving under N_2, Ar**
- **O_2 level below 30 ppm**
- **Precise temperature uniformity**

HTK Metallic Chamber Furnace for Powder Injection Molding and Additive Manufacturing

- **Debinding and Sintering under H_2, Ar, N_2**
- **Switchable gas flow for processing of sensitive materials**
- **Fully automatic control system**

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