HIP – a Partner for MIM, CIM and AM

Innovation in Hot Isostatic Presses (HIPs) for post-compaction of components originally formed from metal powders. HIPs are machines operated at high temperature and high pressure. Developed in the USA in the 1940s and 1950s for the production of nuclear fuel elements, they have evolved from specialised applications to become a standardised industrial process today. Almost 1000 such presses are in operation in various applications worldwide. In industrial applications, pressures up to 310 MPa and temperatures up to 2200 °C are possible today [1].

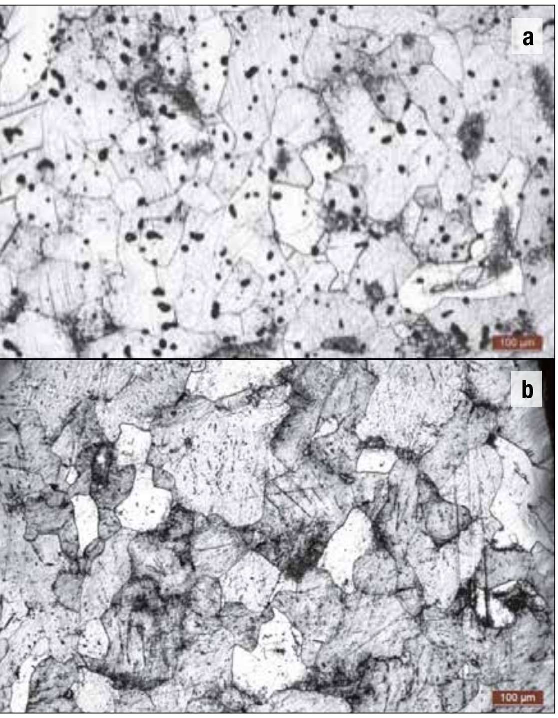

Fig. 1
(a) Ti before HIP (b) Ti after HIP

Introduction

Hot Isostatic Pressing is a well-established method for the post-processing of a large range of porous parts and as a direct shaping process for powder metallurgical components made with metal powders.

Keywords
HIP (Hot Isostatic Press), MIM (Metal Injection Moulding), CIM (Ceramic Injection Moulding), AM (Additive Manufacturing)

During Hot Isostatic Pressing (HIP) the parts to be processed are heated up under a high-pressure argon atmosphere. The isostatic gas pressure exerts high forces on the entire outer surface of the parts being treated while simultaneously the high temperature lowers the yield point of the material. The pressure and temperature thereby lead to diffusion and homogeneous microstructural compactions within the material.

For most materials, the process pressure is approx. 1000 bar = 100 MPa and temperatures are up to 1400 °C.

The HIP process serves to remove internal cavities, e.g. residual pores in cast or sintered metal or ceramic parts, in order to obtain material properties comparable to those of forged parts.

Usually, argon is used as the pressure transmitting medium at material-specific Sinter Temperatures (TS), i.e. approx T_s = 0,7. Depending on the material, the applied pressure varies between 300–1500 bar. This pressure is achieved by means of a compressor as well as by taking advantage of the increasing pressure due to the thermal expansion of the gas.

Applications

HIP-produced or treated components show the following properties:

- isotropic, homogeneous, and pore-free micro-structure (100 % density),
- no internal material defects as a matter of principle respectively their avoidance and recovery (cavities, cracks, pores),
- considerably improved mechanical properties, especially fatigue strength,
- considerably improved polishability.

Therefore, the HIP process is successfully used for the following applications:

- redensification of all PM-parts (conventional metal or ceramic sinter parts, MIM-parts, CIM-parts and AM-parts) to eliminate pores,
- general redensification of cast or forged parts to increase their performance or to recover defects,
- near-net-shape production of Powder Metallurgical (PM) parts and semi-finished products by means of the container method,
- processing and densification of materials, which can only be processed by means of powder metallurgy, e.g. carbides and various super alloys.

HIP system – general makeup

A HIP can be also understood as a high-pressure furnace. This furnace accommodates the product to be processed, heats it up to the desired temperature, and at the same time shields the outside against this temperature by means of its insulation.

This happens under very high pressure (up to 2000 bar). The furnace itself could not withstand the pressure. Consequently, the complete furnace is located inside a pres-

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sure vessel (= recipient + top and bottom closure + closing frame) (Fig. 2).
Thus, the furnace and therefore its individual components are subjected to isostatic pressure only, i.e. from all sides at the same time. Therefore, there are no high mechanical forces due to the pressure acting on the furnace components. As a result, the furnace can neither explode nor implode.
The pressure vessel is responsible for accommodating the furnace and withstanding the process pressure. The furnace insulation protects the pressure vessel against the process temperatures.
Other sub-systems of a hot isostatic press are:

- compressor – to pressurize the process gas to the desired process pressure inside the pressure vessel,
- vacuum system – alternatively evacuating and purging the pressure vessel with fresh process gas to remove undesired oxygen prior to the HIP cycle,
- cooling system – to cool the pressure vessel,
- hydraulic system (on larger HIPs if needed) – to open and close the pressure vessel etc.,
- gas supply system – for example a high-pressure valve rack,
- recycling gas deposit (if needed) – to store and recycle process gas with the aim of reducing the gas consumption of the system,
- system control (PLC) with human-machine-interface (visualisation).

CREMER's HIP design philosophy
Furnace design
The furnace is the most critical system of a HIP. It's design and quality has a direct influence on the quality of the resulting processed material or final product.
Therefore, the quality and functionality of the furnace is one of the author´s top priorities. The reliability, operational safety, maintainability, and ergonomy of this component are the main aims taken into account during the design process.
One of the fundamental features of the CREMER furnace system is that it is not permanently mounted into the pressure vessel. Instead it is removed from the HIP unit for loading and unloading.
The furnace is therefore an independent system unit which connects automatically

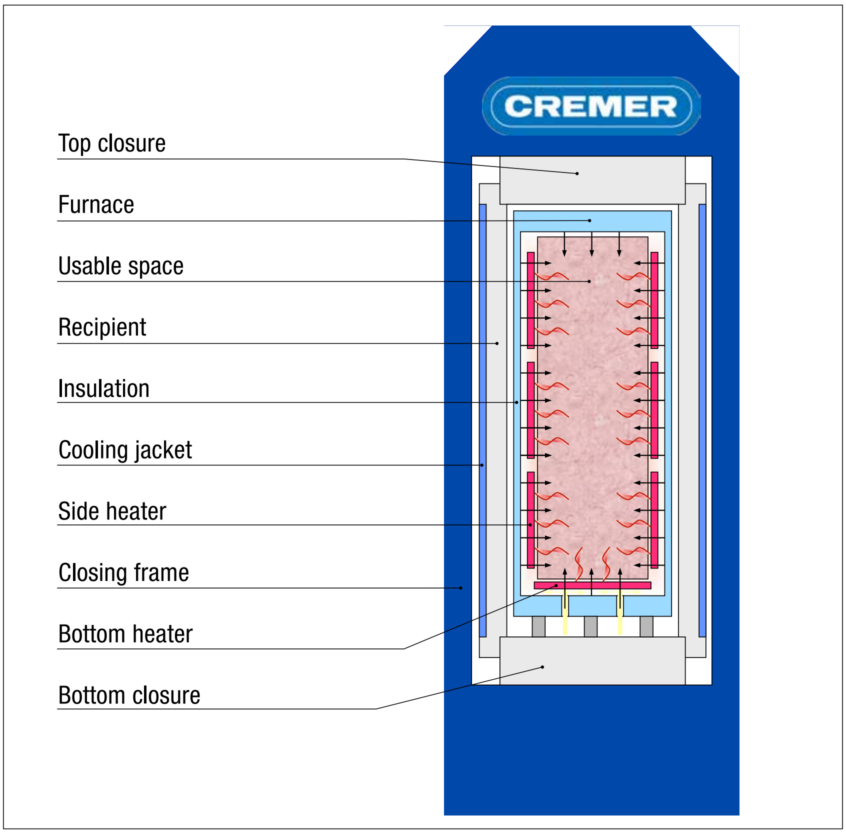

Fig. 2
Vessel overview of the CREMER HIP

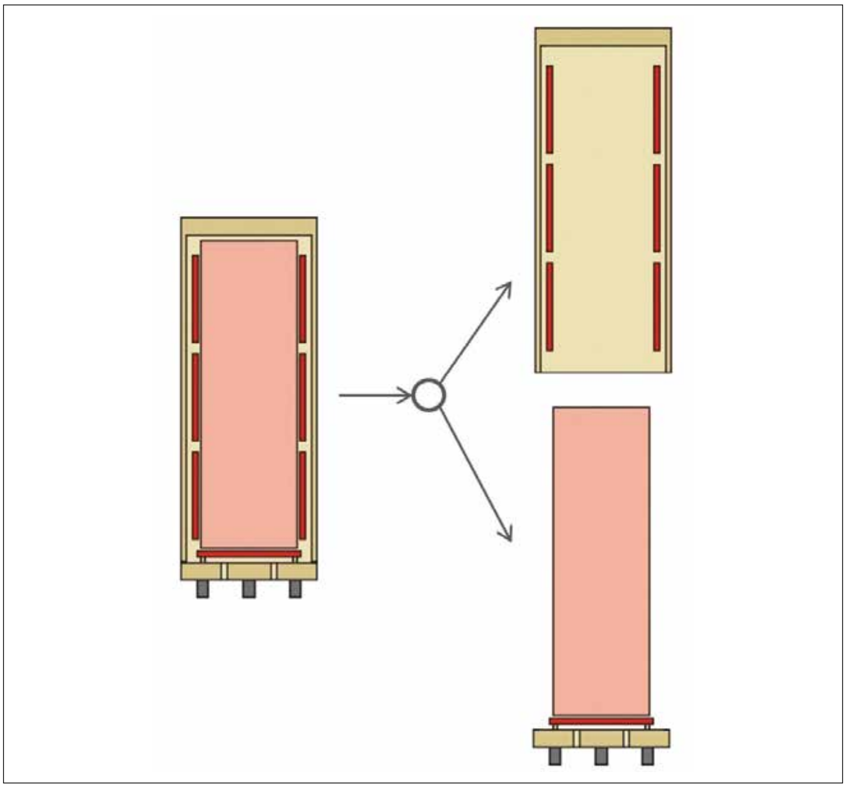

Fig. 3
CREMER furnace system overview

to the rest of the system over plug connections when it is placed in position inside the pressure vessel.

The furnace unit is moved out of the HIP pressure vessel completely by means of a crane and put onto a mounting nearby the position of the HIP unit. Thereafter, the operator unlocks several locking mechanisms between the insulation cover and charge carrier. In the next step, the operator takes the insulation cover off the charge carrier (Fig. 3). Once the furnace is open, the batch is accessible for loading and unloading.

Superficially considered, removing the complete furnace out of the pressure vessel might seem to be more cumbersome than leaving the furnace unit in the vessel and simply removing the process product out of the HIP through a suitable access to the inner loading space.

However, when looking closely, it becomes evident that the CREMER design has various decisive advantages which will pay off for the customer:

- Ergonomy: when the charge carrier is placed on the mounting device, the operator can load and unload the batch on a comfortable working height. This is much more convenient and safer than for example bending down into the open vessel to reach the parts.
- Automation: because of the very good accessibility of the batch, automation of the loading and unloading process can be obtained very easily.
- Efficiency: a second furnace unit can be prepared i.e. loaded, while the HIP unit is still processing. At the process end, the first furnace can be taken out and without any delay the second furnace unit can be put directly into the vessel and the process can be started again. This procedure is a possibility to save time during production and increase the productivity of the system.
- Quality checking: depending on the application (e.g. aerospace, medical technology) the furnace thermocouples must be replaced frequently for maintenance or quality assurance. The detached furnace allows the operator a quick access.

Furthermore, the furnace and the interior of the pressure vessel can be checked or cleaned in between process cycles, completely barrier free.

- Maintainability and production reliability: As explained, the system consists of a number of furnace units for the same pressure vessel body. This allows the operating company to have a backup furnace unit in case of an unrepairable failure. At the same time it is possible to send in one specific furnace unit for overhauling to us without stopping the production.
- Flexibility: different furnace types can be used without any modification, according the required process temperature.

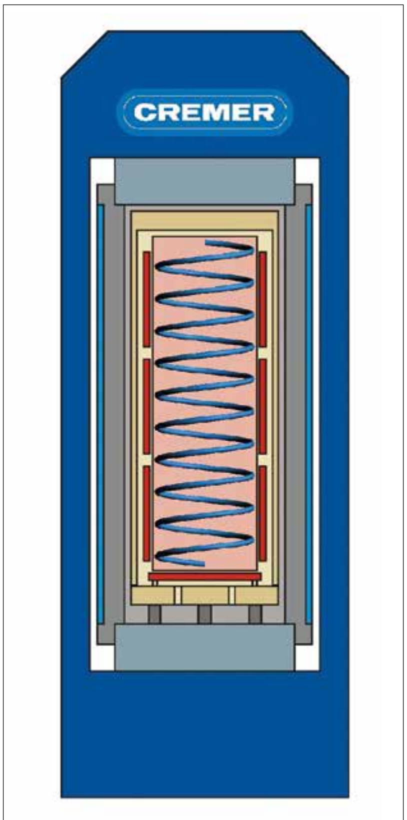

Fig. 4
Rotating cooling swirl

Interchangeability of the furnace and type of thermocouples

Various materials demand varying process temperatures, thus leading to varying requirements for the implementable furnace process parameters.

Consequently, our product range offers a graphite furnace (G200), a molybdenum furnace (M140), and a predominately steel furnace (E105). Each individual furnace type features different properties:

- M140 – molybdenum furnace: for high temperature applications up to 1400 °C and zero tolerance for carbon vapour in the atmosphere, e.g. for processing stainless steel.
- G200 – graphite furnace:
  for maximum temperatures of up to 2000 °C, e.g. for ceramics.
- E105 – FeCrAl furnace:
  cost efficient alternative to the M140 furnace, for applications with relatively low process temperatures of up to 1050 °C (for e.g. aluminium alloys). With this furnace it is also possible to work with added oxygen in the atmospere.

Generally, an issue that also needs to be considered when changing the furnace type is the fact, that each furnace type is equipped with suitable thermocouples (type K, S, C, etc.) depending on its maximum process temperature.

The possibility of changing from one furnace type to another at any desired time is one of the outstanding features of our system. Changing the type of thermocouple for temperature measurement is no issue in the CREMER system. Mechanical modifications are not necessary. The operator simply switches the system control to the furnace type in use.

Consequently, the operating company is not tied to a certain product material group.

Active rapid gas cooling

Due to the much denser atmosphere inside a HIP, the cooling process differs a lot from a conventional (low pressure) furnace. If the heaters are simply switched off after the HIP process, the temperature at the bottom of the furnace will drop very sharply while the temperature stays high at the top of the insulated furnace for long time.

Such temperature inhomogeneity fatally affects the quality of the batch. Furthermore, it prolongs the HIP cycle time as the furnace takes a long time to cool down sufficiently to be exposed to air.

Without any active cooling system providing artificial convection, the only way to prevent an uneven temperature distribution is to keep the bottom heating slightly active till the end of the cooling phase. Consequently, this always leads to very long cooling phases and cycle times in total.

To avoid unnecessary long cooling phases, the CREMER HIP is commonly equipment with an newly developed active gas cool-

ing system. The specific feature of this gas cooling system is an excellent temperature homogeneity during the cooling process and across the complete usable height of the loading chamber.
This uniformity generated by a rotating swirl of cold process gas inside the loading chamber (Fig. 4). Thus, the processed product is not impinged by one concentrated cold gas jet. Instead, the cold process gas mixes homogeneously with the hot process gas to a full extent for to the complete height of the loading chamber.
Another specific feature is the controllability of the cooling rate:
In many applications too high cooling rates are strictly prohibited. A quick, but not too quick, but definitely uniform cooling is required. The CREMER controlling system actively adjusts the cooling rate to control the cooling throughout the entire cooling phase, while the cooling takes place uniformly for the whole height of the batch.

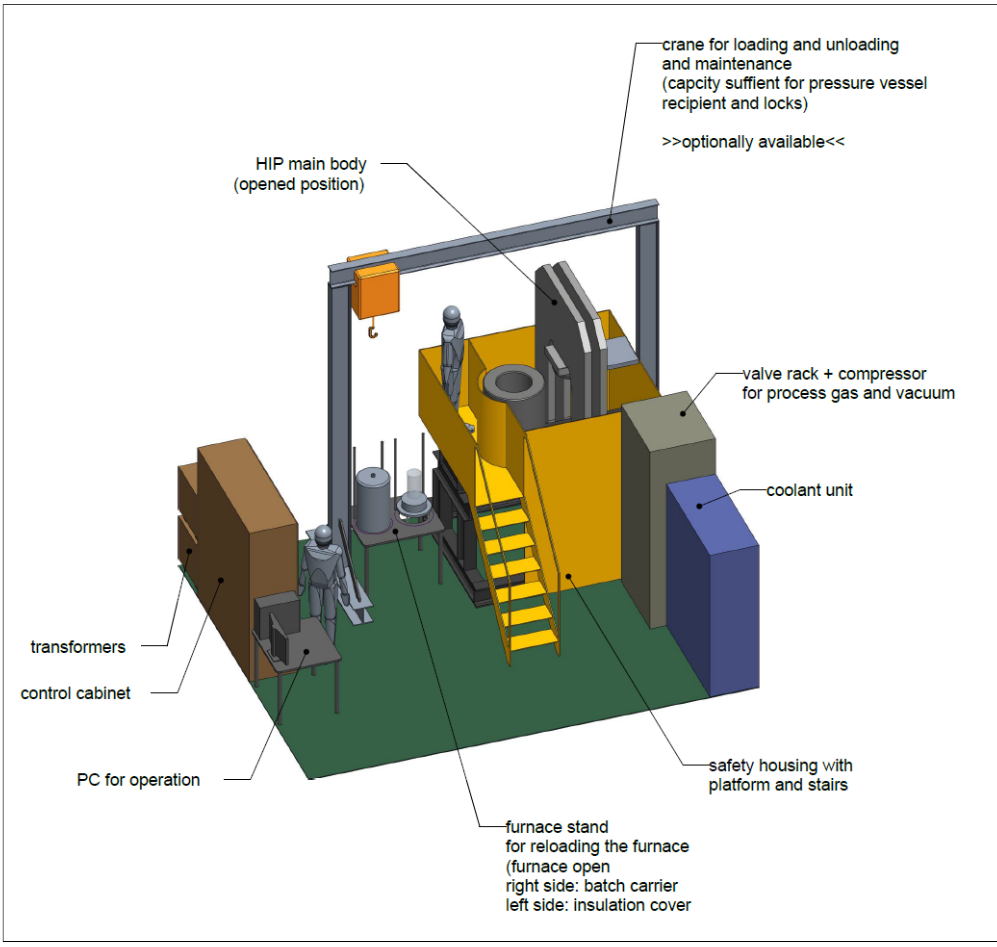

Fig. 5
Example of a production layout of a small CREMER HIP unit

Operability – maintainability – design
Besides the basic obvious features of a HIP, such as working temperature and working pressure, many other features of a machinery system need to take the fundamental following objectives of the operational company into account.
Design objectives are:
- investment costs,
- operational staff costs,
- maintenance costs,
- needed space for all installations.

In most cases, a compromise has to be found in order to find the best solution. An example is shown in Fig. 5.
A HIP for daily mass production of identical parts and materials should have a minimum cycle time and minimum operational costs for staff, energy and gas supply. Therefore the HIP needs a high grade of automated functions and maybe even a system which will recycle the process gas after the HIP cycle.
Consequently additional systems for automation and recycling will demand higher maintenance efforts. But that is acceptable as the machinery is permanently in use and generating values.
In contrast, a HIP that is used for very individual products or for laboratory purposes has other priorities: probably the HIP will not run day by day. Also the sorts of process materials and also the customers will vary often. In these scenarios using recycled gas might be prohibited. So a recycling gas system probably won't pay off. And as the process batch varies, a high grade of expensive automation is probably too inflexible and therefore inefficient as well.
On the other hand, especially in laboratories, space is very limited. All machinery should be as compact as possible. This is certainly easier to achieve, if the machine is not equipped with many automated functions. That safes space in two ways: firstly, because of the missing automation devices themselves. Secondly, actions carried out by hand often do not require additional safety devices such as fences or light barriers. In addition, these facts mean that general maintenance costs will be reduced as well.

Reference
[1] Broeckmann C.: Entwicklung der HIP-Anlagentechnik, Proceedings Symposium Hagen 2011