HIP – a Partner for MIM, SLS and AM Innovation in Hot Isostatic Presses HIP for Post-Compaction of Components Originally Formed from Metal Powders

Hot Isostatic Presses (HIP) 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].

Introduction

Under uniform (isostatic) gas pressure from all sides, the components are compacted practically pore-free and at the same time they are furnished with isotropic properties. HIP is a complex and correspondingly expensive manufacturing or after-treatment process.

Thanks to its wide flexibility with regard to the achievable component size and geometry and the excellent component properties that can be obtained, HIP has been established in mass production and in the production of individual high-performance components all over the world.

Parallel to this, Metal Injection Moulding (MIM) and Additive Manufacturing have been established as processes for the fabrication of complex metal components.

Owing to the nature of the process, such components contain a high percentage of pores. Depending on the purpose of the components, these pores may be undesirable as they might form the starting points for defects and might impair mechanical material properties.

Keywords
HIP repressing, metal injection moulding, selective laser sintering, additive manufacturing

Combining components originally powder metallurgically formed with the HIP process, new possibilities are opened up to manufacture pore-free and high-strength components at low cost.

This offers a viable alternative to classical forging and machining. As universal service providers, today's HIP systems are developed to cover as many applications as possible. This makes them very versatile in use. However, HIP systems are very large and also cost-intensive in acquisition and operation. A system design optimised for the described processes can compensate this disadvantage.

New concept for HIP systems

CREMER Thermoprozessanlagen GmbH/DE has developed such a HIP installation. Various approaches were researched for this purpose. First, the actual process must be developed to identify the physical boundaries, in which the operators can optimise their process cycles.

This applies especially to the expected maximum pressures and operating temperatures, for which the system has to be designed. This is done by literature research and real tests.

The resulting findings allow conclusions, on the basis of which the optimum recipient (pressure vessel) can be developed and its manufacture can be defined. The same applies for the furnace.

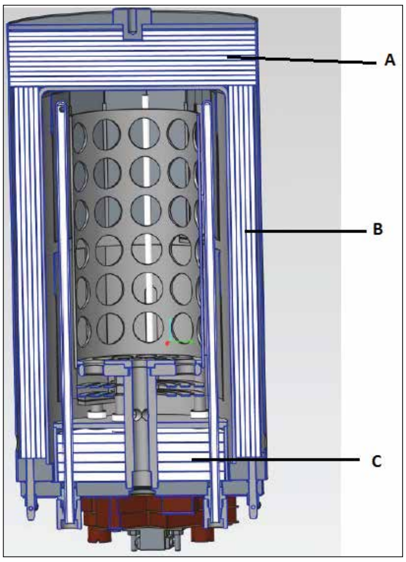

Fig. 1
Mo-heating and insulation hood

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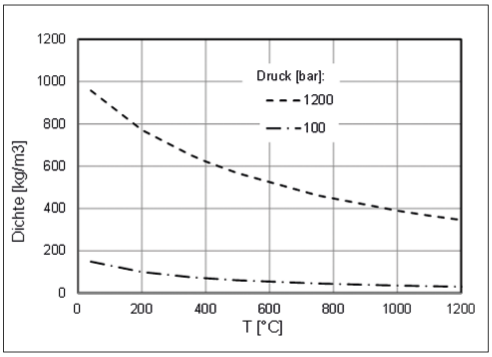

Fig. 2
Argon density

Fig. 3
Cyclone flow

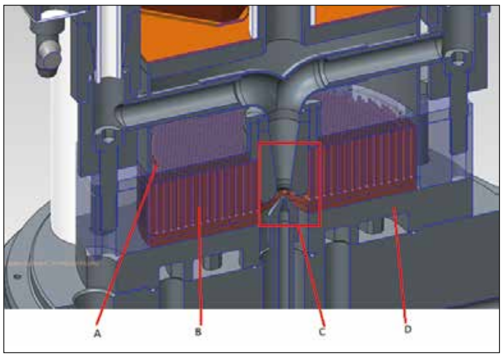

Fig. 4
Heat exchanger

The goal of the tests was optimising a HIP process in terms of quality (density of the finished product) and costs (lowest possible temperature and pressure).

To this end, valuable first results could be obtained for five tested materials.

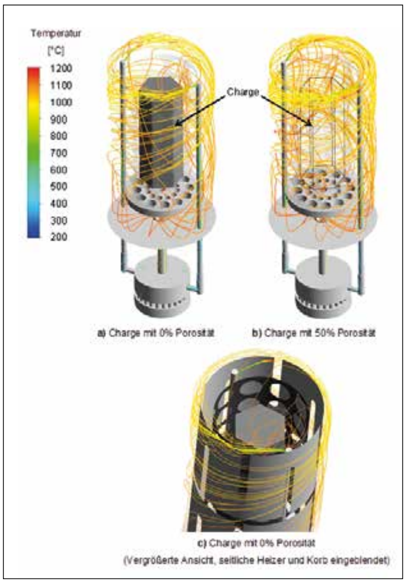

Fig. 5
Excerpt from the simulation

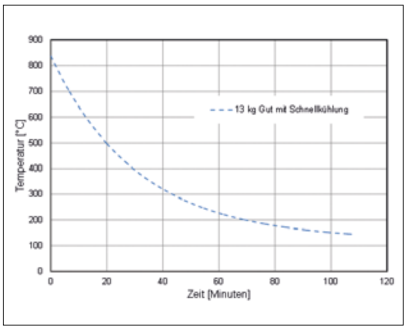

Fig. 6
Transient cooling curve

- austenitic stainless steel 316LA;
- nickel steel FN08;
- soft magnetic alloy FeSi3;
- nickel superalloy Inconel 713;
- precipitation-hardened stainless steel 17-4PH.

For post-compaction, pressure appears to be the crucial parameter. The literature research confirmed this [2].

Pressure seems to have a greater effect than longer holding times or higher temperatures. At 80 MPa, comparable or higher relative densities could be proven consistently. Thus, it is advisable to design systems for maximum working pressures of 100 MPa for the described application. Pressure vessels for 100 MPa can be fabricated with the same method as those for 80 MPa. Thus, the higher design pressure can be regarded as the machine reserve.

Basing on the test findings and the work, CREMER Thermoprozessanlagen set the maximum temperature for such a system at maximum operating temperatures of 1150 °C.

Accordingly, low-cost heat-resistant stainless steels can be used as batch carriers.

A molybdenum heating system is used, which is indeed more expensive than heating with ferritic stainless steel (e.g. Kanthal A1). This way, however, more heating power can be installed. This shortens the process time, which clearly offsets the cost disadvantage.

The batch carrier with interior heating is radially and axially covered with a molybdenum hood at the top. It is specially divided into segments to minimise deformation. For thermal insulation on the outside, a combination of ceramic soft felt and metal foils (molybdenum or stainless steel) is used. The felt is used for thermal insulation while the foil prevents gas convection through the open felt.

The insulation consists of three such radially arranged layers. The cover insulation consists of five layers. The hood is completed with a lid and stainless steel jacket. FEM calculations were applied for multidimensional heat transfer. A section of the insulation is shown in Fig. 1.

A master thesis has shown that the flow in a HIP system can be simulated. Here, constant argon parameters are used [3]. In the HIP, however, these intensive values are not constant, which has a strong effect on the flow. For this reason, in this work a state equation for argon is used by the researchers around the Tegeler group [4].

On this basis, a very accurate approximation of how argon behaves realistically at different pressures and temperatures. Here, not only density but also viscosity and heat transfer are examined. Within the scope of this work, a software was programmed, which calculates the state variables for argon for the different points in the simulation, and which is basing on the scientific paper of Tegeler, et al.

Rapid cooling

A HIP cycle has fixed times, which are determined based on physics. There are also design-related times in the cycle, which are derived from the model of the system. Here is the answer to the question of how these times can be shortened cost efficiently.

With a solid simulation model, rapid cooling can be designed. After the cycle, the system can be cooled down faster. The shorter the overall cycle from loading to unloading of the material treated, the smaller the system for a given capacity. Size is a key cost factor

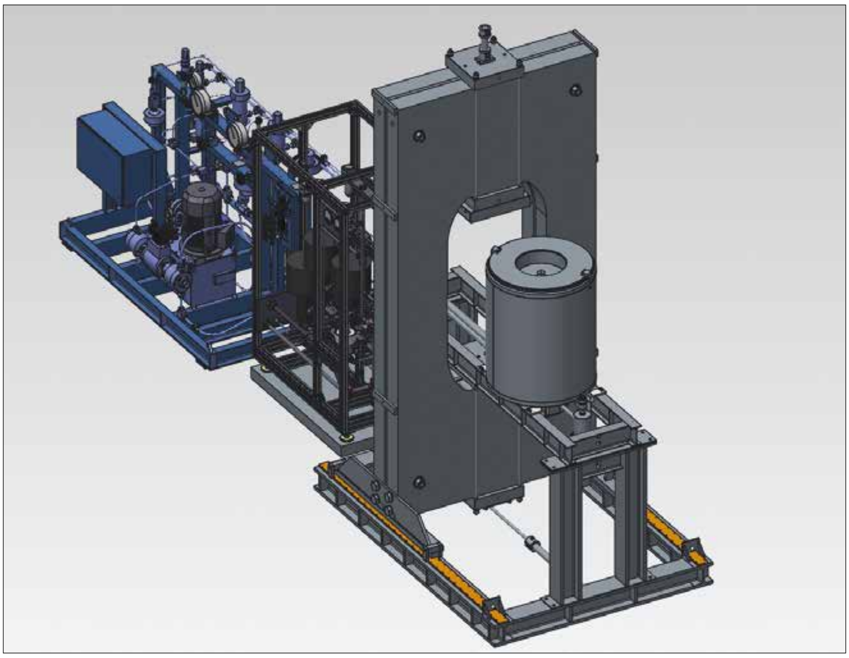

Fig. 7
New HIP system

for HIP systems. Therefore, special attention is paid to shortening the process time. A proprietary patent DE 10 2007 023 699A1 2008.11.27 is applied to generate a cyclone flow (Fig. 3). A heat exchanger is integrated in the bottom plate – the bottom closure (Fig. 4).

The simulation showed that process time can be reduced significantly (Fig. 5). The model also shows considerable optimisation potential, so that heat treatment based on rapid cooling can be integrated. Cooling rates of 2–8 K/s should be possible. To this end, other studies are under conduction (Fig. 6).

The findings gathered from the studies above resulted in the building of a “proof of concept” system, which has now been delivered and which should prove the determined parameters (Fig. 7).

Outlook

The combination of HIP and powder metallurgy will open up new applications in aviation, the CCC industry, the medical sector, and other business areas, where components capable of withstanding high stresses are required. Just think of pore-free implants or lightweight solid turbine blades fabricated with printers.

A new generation of hot isostatic presses makes this combination economically efficient.

References

[1] Broeckmann, C.: Entwicklung der HIP-Anlagentechnik. Symposium des Fachverbands Pulvermetallurgie in Hagen, 2011

[2] van Kempen, S.: Optimum HIP parameters for 17-4PH. Lit. survey and general planning. Aachen 2013

[3] Akerberg, A.: CFD analysis of the gas flow inside the vessel of a hot isostatic press. M.Sc. Thesis, KTH School of Industrial Engineering and Management Energy Technology. EGI-2012 Division of Heat and Power Technology SE-100 44 Stockholm, 2012

[4] Tegeler, Ch.; Span, R.; Wagner, W.: A new equation of state for argon covering the fluid region for temperatures from the melting line to 700 K at pressures up to 1000 MPa. J. Phys. Chem. Ref. Data **28** (1999) 779–850

[5] Cremer, I.: HIP as Partner for MIM, SLS and AM. Innovations in hot isostatic presses HIP for post-compaction originally formed from metal powders. cfi/Ber. DKG **93** (2016) [10] E 15–E 17