Aalberts Surface Technologies

Hot Isostatic Pressing (HIP)

April 2024

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Introduction to HIP

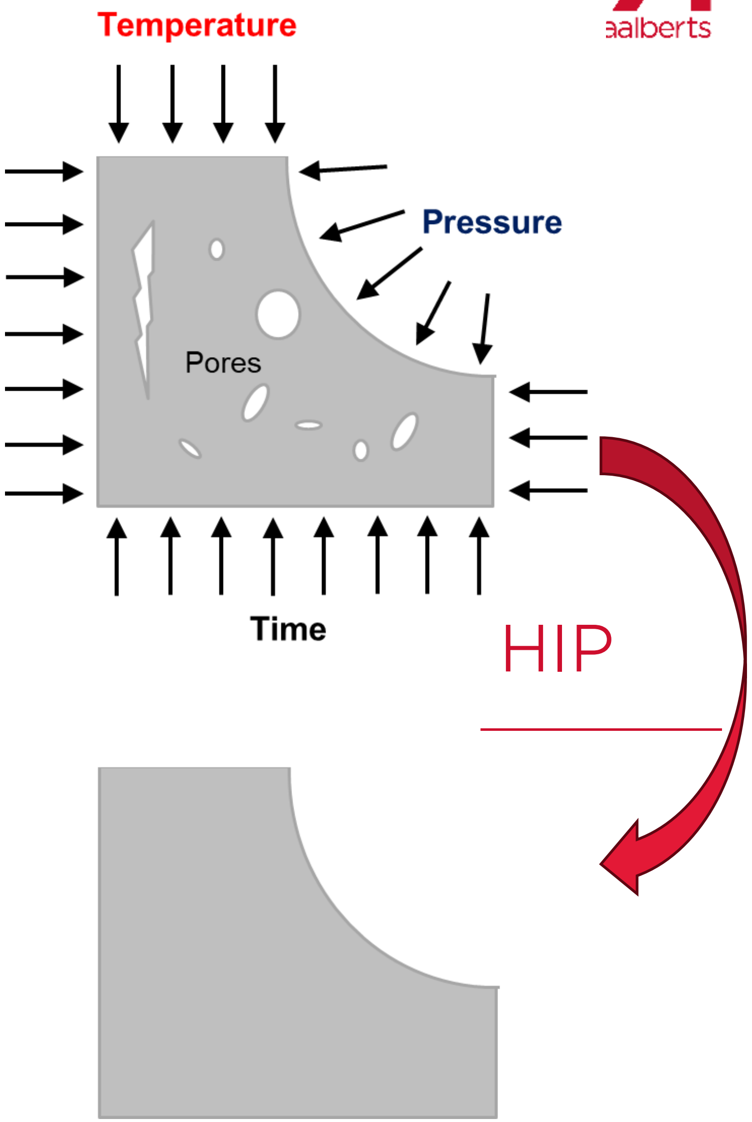
Hot Isostatic Pressing (HIP)

Source: Quintus Technologies AB

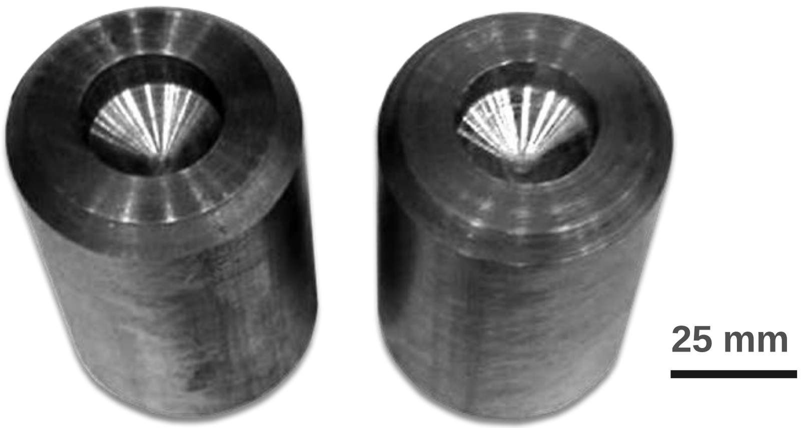
- Simultaneous application of a high-pressure gas and an elevated temperature
- In a specially constructed vessel, the pressure applied is isostatic because it is developed with a gas
- Under these conditions of heat and pressure internal defects within a solid body collapse and weld up

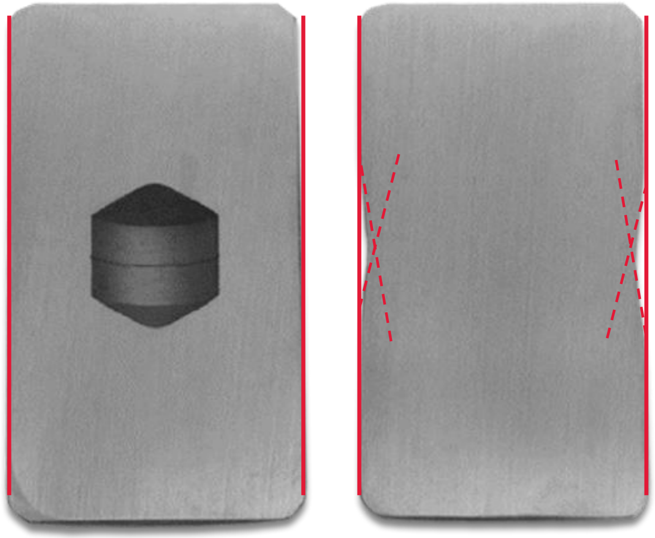
Hot Isostatic Pressing

- Definition: “Applying a pressure, distinctly higher than the yield strength of the material at the HIP temperature”
  - Temperature and pressure up to 2000°C and 207 MPa
- HIP is used for the densification and elimination of **internal porosity** in cast, additive manufactured (AM) and sintered material
- Mechanisms:
  - Mechanical deformation
  - Creep
  - Diffusion
- Isostatic pressure conditions
  - Inert gas as pressure medium, usually Argon
  - Same pressure acting on all surfaces in all directions



Example: Fill in the gaps





Source: Quintus Technologies AB

Artificial pore was closed but the material had to come from somewhere

- Two halves of a cylinder, each with a drilled 1” diameter hole welded together
- Potential dimension change depends on vol.% of porosity
- 1% Porosity → 1% Shrinkage by volume
- Shrinkage is evenly distributed if porosity is evenly distributed

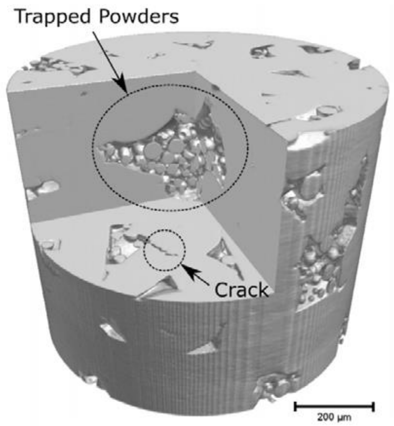
Applications of HIP

Application	Goal	Material
Densification of (investment) castings and additively manufactured parts	-To remove macroporosity and microporosity	Ni- and Co-based superalloys Ti alloys Al alloys Steels Cu alloys
Densification of pre-sintered powders	-To achieve full theoretical density and to avoid excessive grain growth	WC hardmetals Si_3N_4 and other advanced ceramics
Consolidations of encapsulated powders	-To achieve full theoretical density and to avoid segregation and excessive grain growth	-HSS steels -Metal Matrix Composites (Al-SiC) -Magnetic materials (ferrites)
Interface bonding	-To diffusion bond similar and dissimilar materials (overcoming problems of conventional joining and uniaxial diffusion bonding techniques) -To bond and densify coatings	-Bronze and steel -Ni alloys and steel -Multi layer structures -Plasma sprayed coatings
Specialized applications	-To remove pores and gaseous impurities from optical materials	ZnS Lanthanides and aluminates

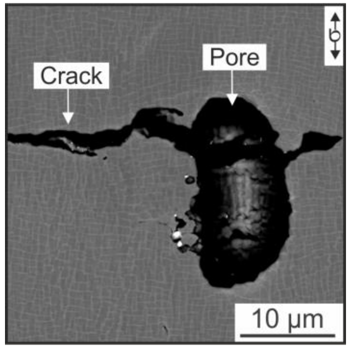
Source: Atkinson, Rickinson, Hot Isostatic Pressing

Example why HIP is performed

- Manufacturing techniques introduce internal defects / porosity
  - Lack-of-fusion defects in PBF-LB / PBF-EB
  - Residual sintering porosity in Binder Jet and MIM
  - Solidification shrinkage porosity (microporosity) in castings & AM
  - Gas porosity
  - Internal cracks
- Internal defects means
  - Stress concentrations
  - Crack initiation points
- Negative influence on material properties
  - » **Pores impair service performance and reliability**



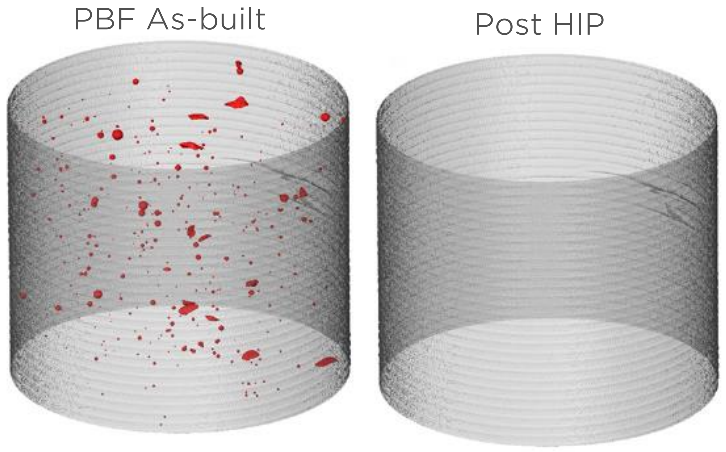
3D view of AM sample with trapped powders in pore spaces and cracks. Source: Kim et al. 2017



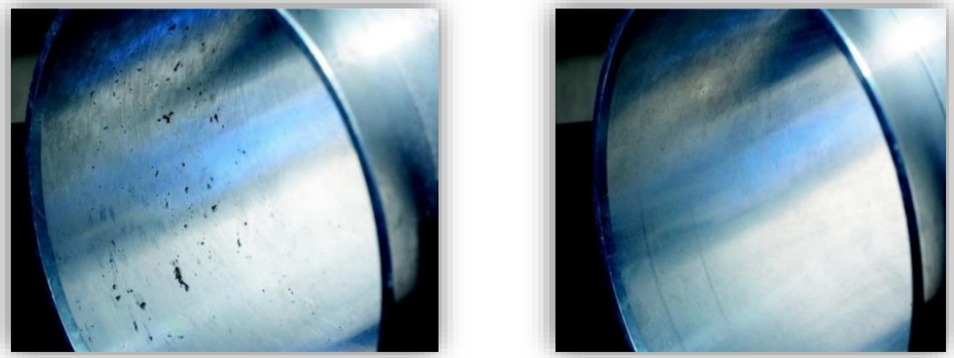
Crack at a pore, „Notch effect".

Benefits of HIP

- Elimination of internal defects gives:
  - Elimination of stress concentrations and crack initiation points
- Superior material properties
  - Improved ductility and fracture toughness
  - Better creep properties
  - Increased fatigue properties, 10 – 100x
- Reduced property scatter
  - The natural variation in defects between components is eliminated
  - More predictive properties
- Improved quality of machined/polished surfaces
  - Important for the sliding surfaces of an implant



Source: Tammas-Williams et al. 2016.



Cast + Machined *Cast + **HIP** + Machined*

Source: Bodycote

HIP & Castings

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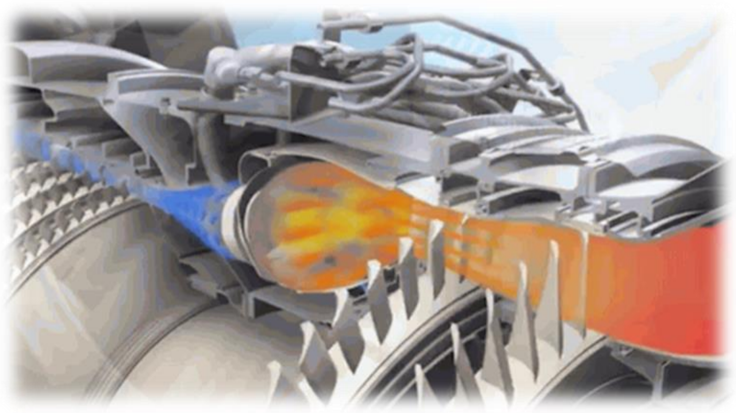
Example: Cast turbine blades in gasturbines



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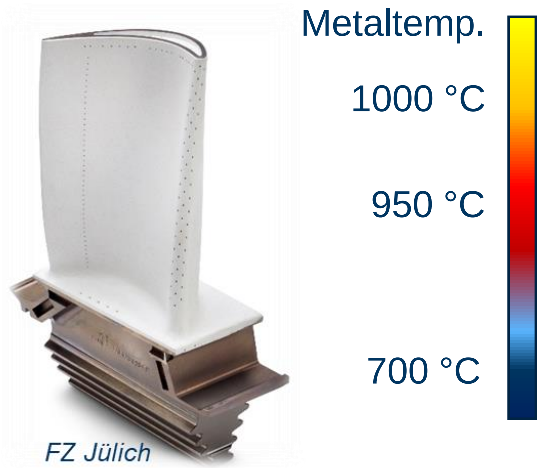
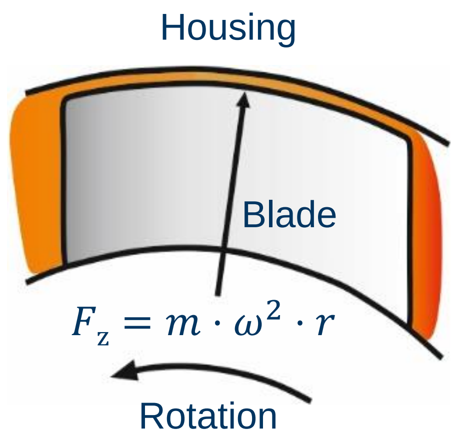
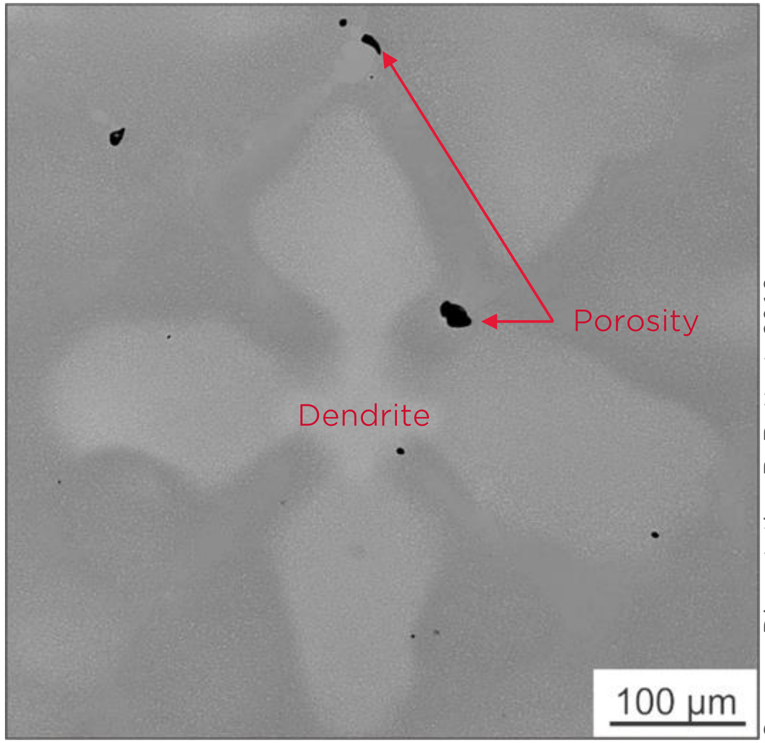


FZ Jülich



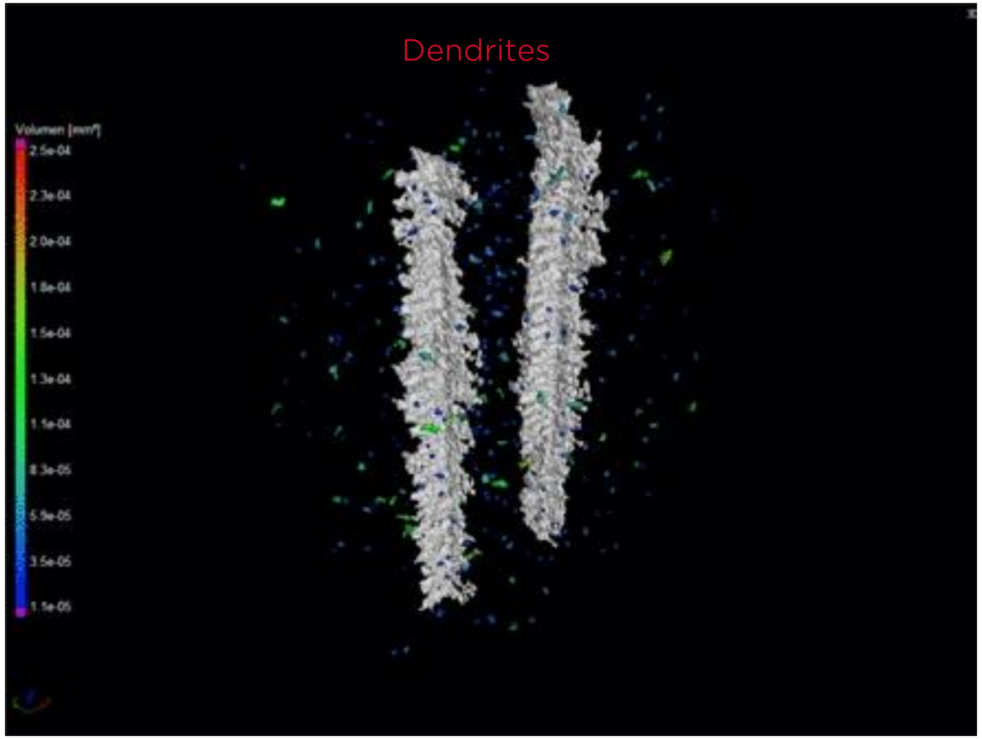
- Example: Blade material in aero engines or stationary gasturbines (IGT)
- Static and dynamic loads during service
  - High centrifugal forces (F_z) at high temperatures, start up and shut down of engines, vibrational stresses

Porosity in castings comes from solidification



Source: Dissertation B. Ruttert, 2019

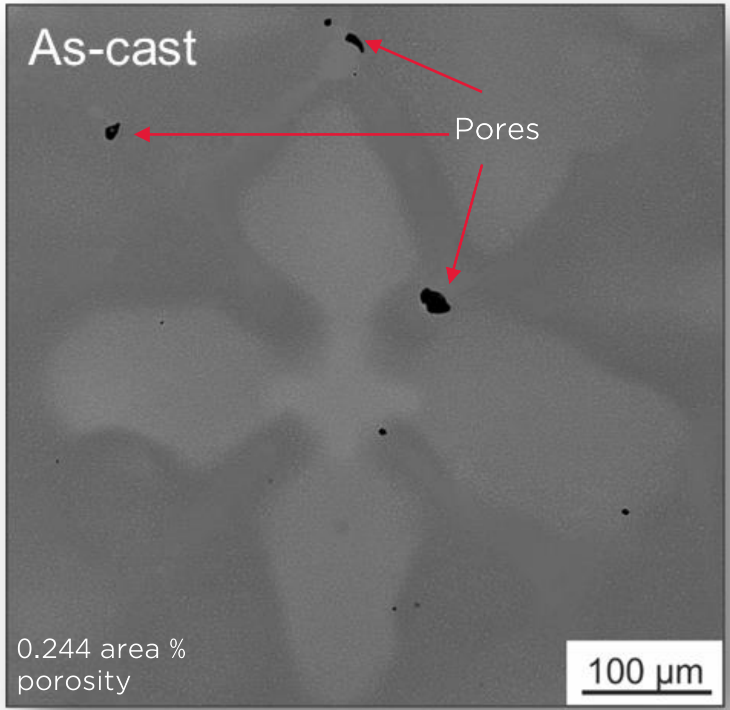
Porosity between a dendrite: 2D SEM



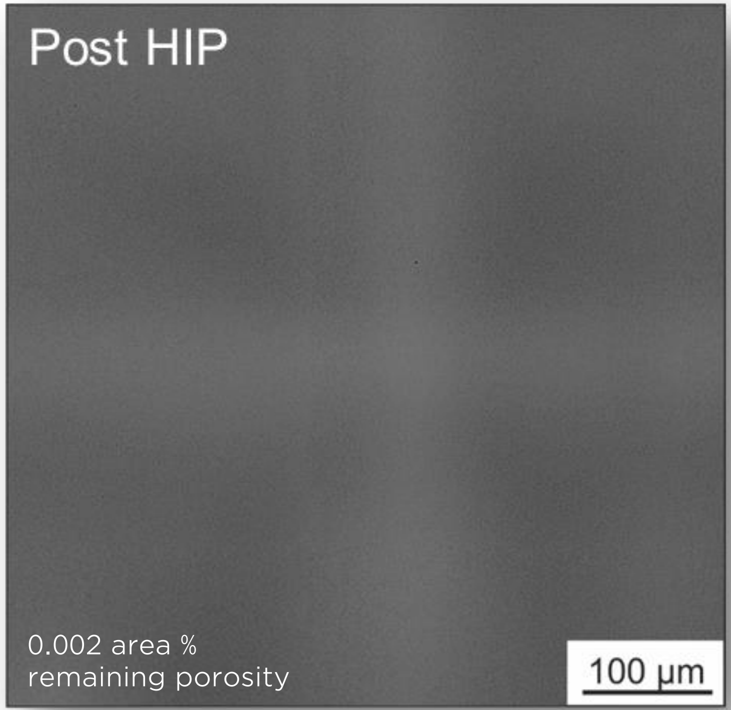
Source: Ruhr-University Bochum, Benjamin Ruttert

Spatial arrangement of porosity between two dendrites: 3D CT

Porosity in castings post HIP

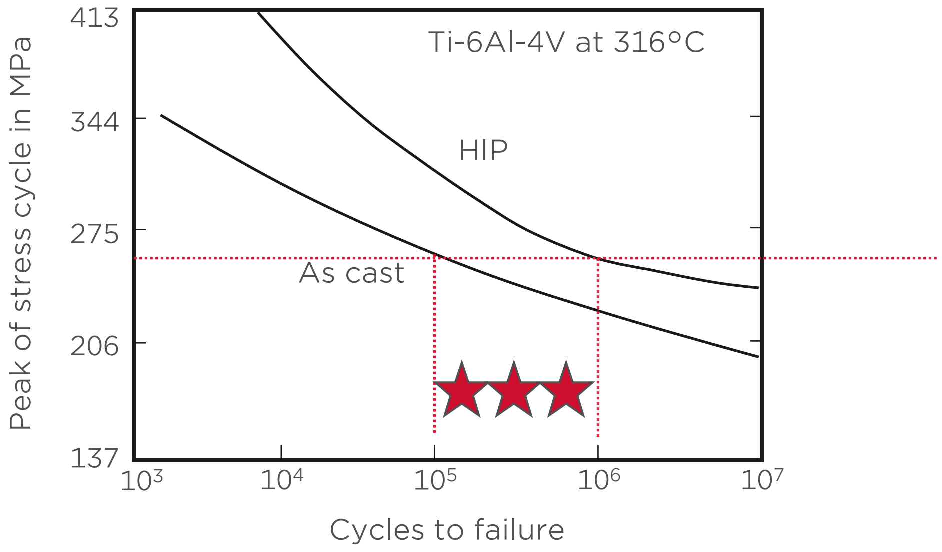


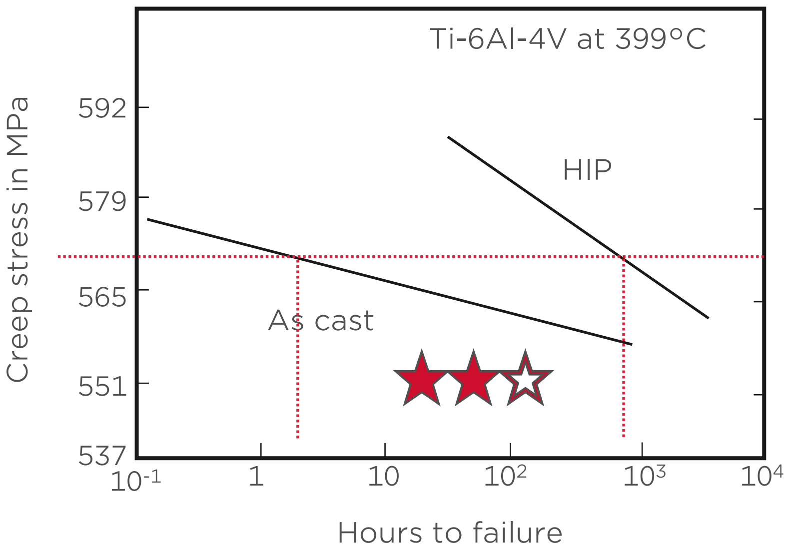
Source: Dissertation B. Ruttert, 2019



Source: Dissertation B. Ruttert, 2019

Impact of HIP on dynamic and static loading





Source: Atkinson et al. 1991

- Example: Blade material in aero engines, low pressure section
- Fatigue and creep resistant materials are important for mission critical applications
- High centrifugal forces at high temperatures, start up and shut down of engines, vibrational stresses

HIP & AM

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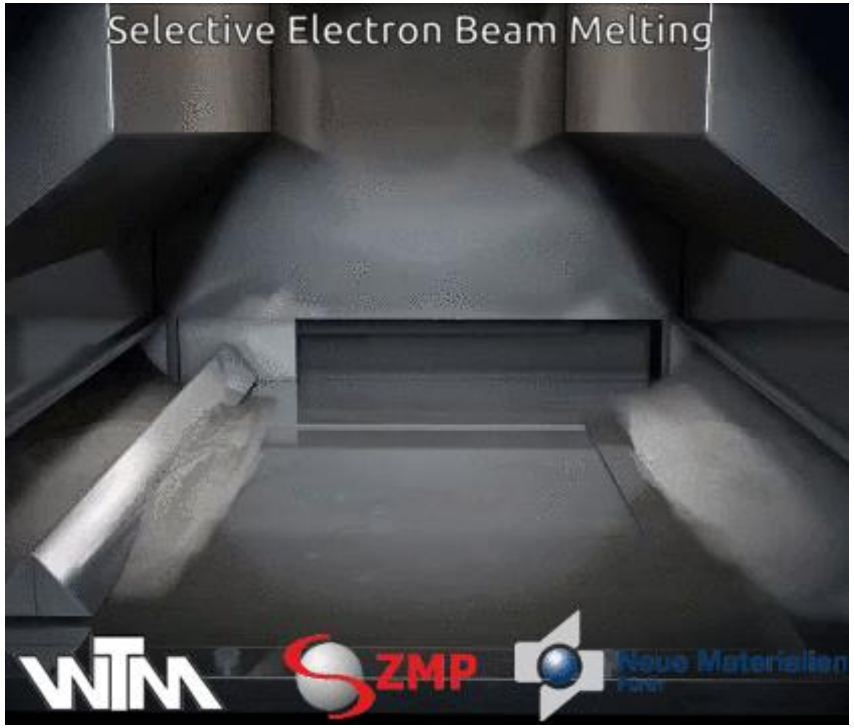
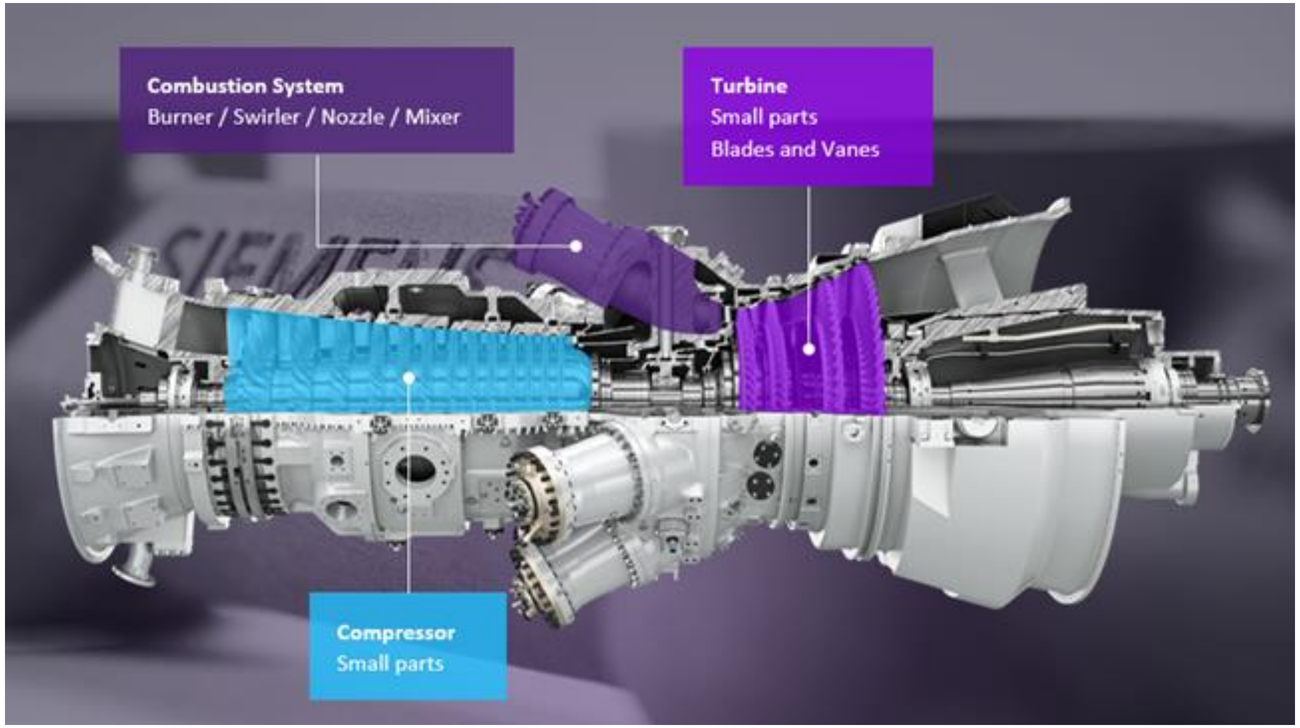
The industrialisation of additive manufacturing (AM)



Source: WTM, ZMP, NMF



Source: Siemens Energy

The challenge for additive manufacturing (AM)

Industry requirements

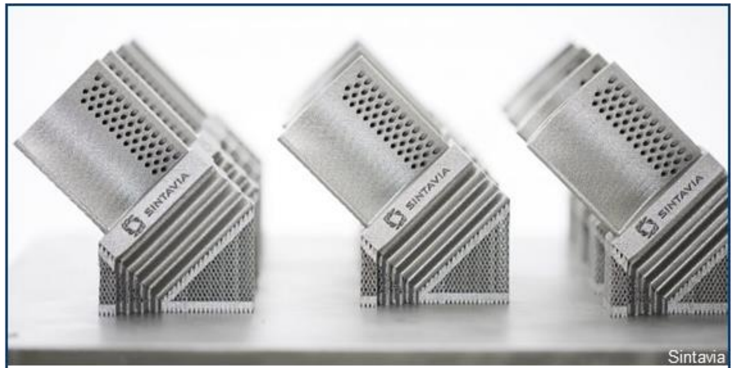
Higher speed

Improved reliabilty

Reduced costs

Larger parts

Typical outcome



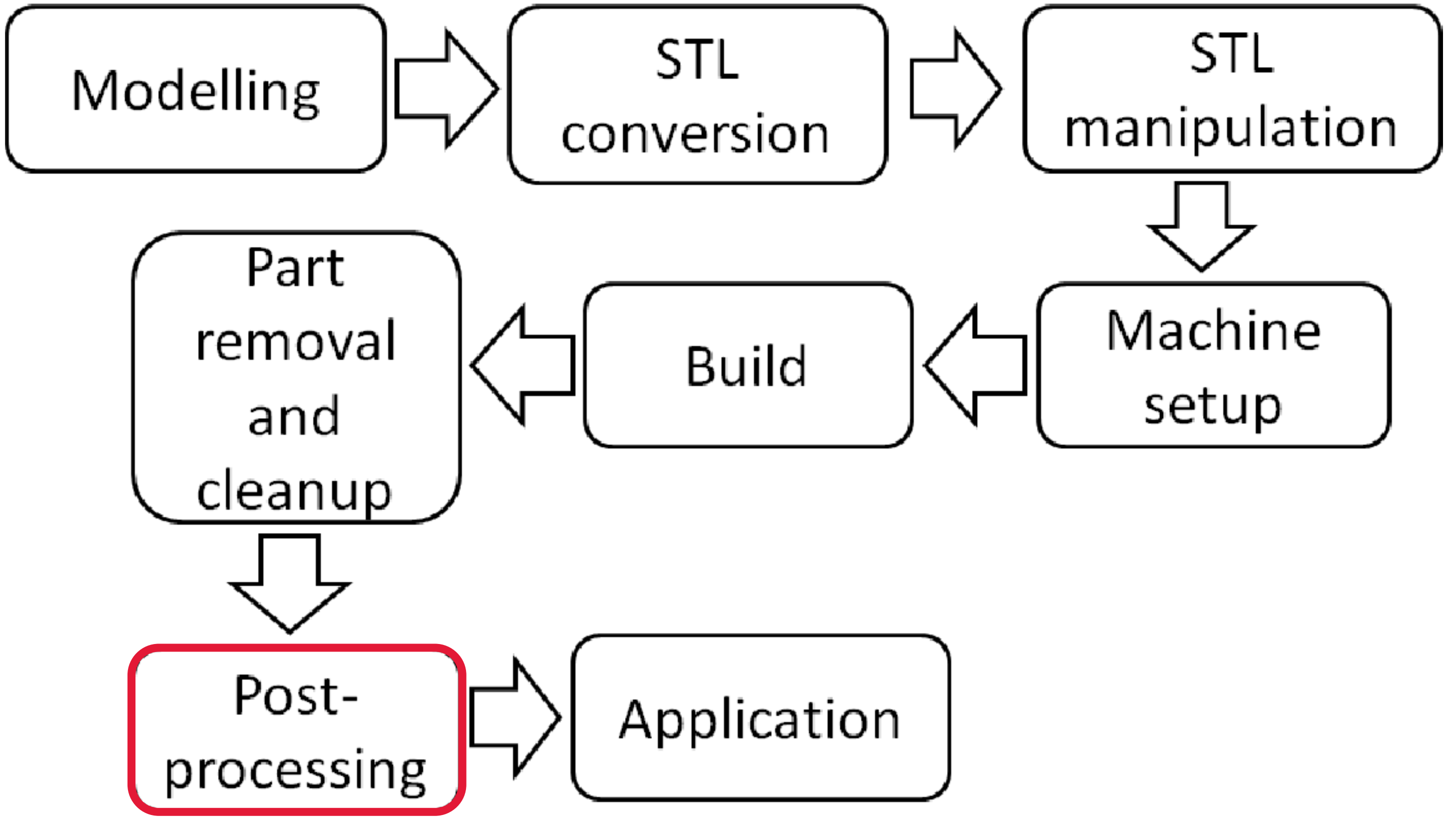
Defects

Porosity

Scattering

Quality costs

The AM process chain



Source: Gibson et al. 2010

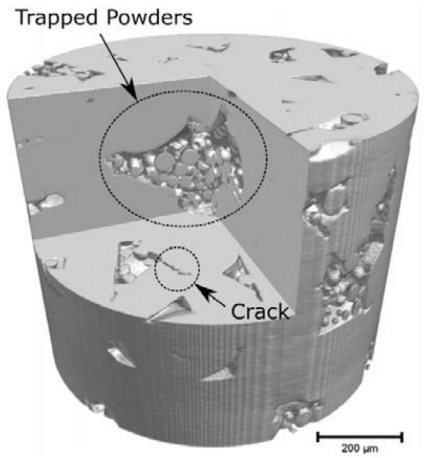
The post-processing route

- Sawing / EDM
- Stress relief
- Solution annealing
- Hot Isostatic Pressing (HIP)
- Machining
- Surface treatment
- Quality inspection

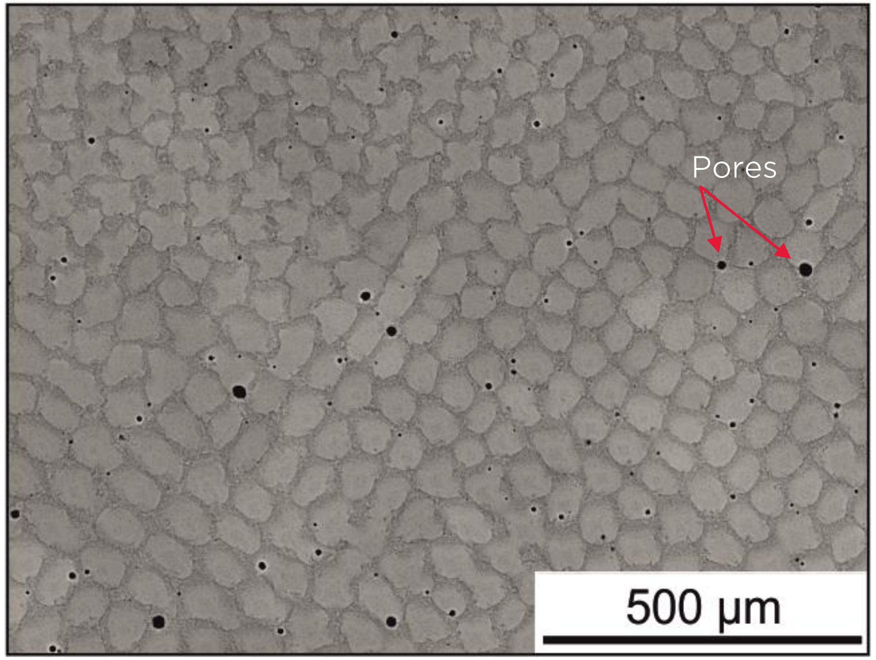
Example: AM Ni-base superalloy for turbine blades

- Formerly classified as non weldable alloys
  - Nowadays Ni-base turbine blades with complex geometries with internal cooling channels are printed
- As-built: Unique microstructure with unique properties
  - Much finer than in cast counterparts
  - New and similar defects as observed in castings (Porosity, chemical inhomogeneities)
- Post processing must be adapted accordingly **(!)**
  - HIP of castings approx. 4h vs. AM approx. 45 min

Source: eos



Source: Heat Treat Today 2021

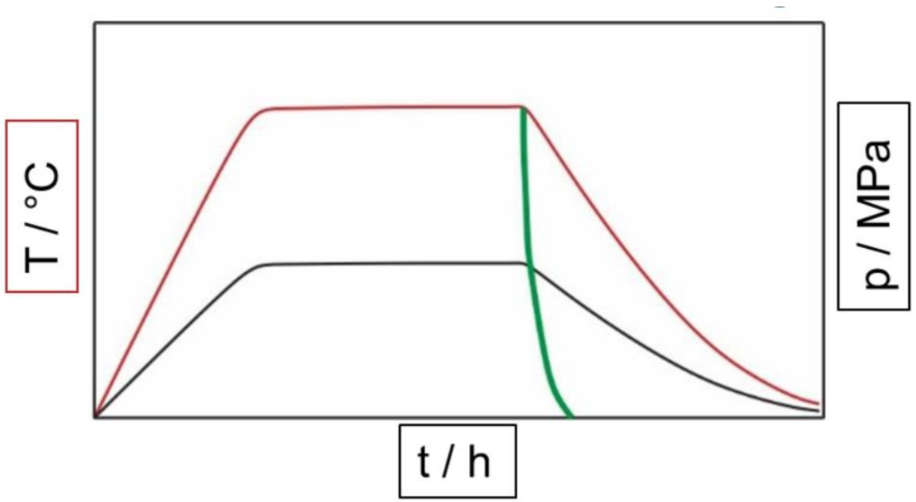


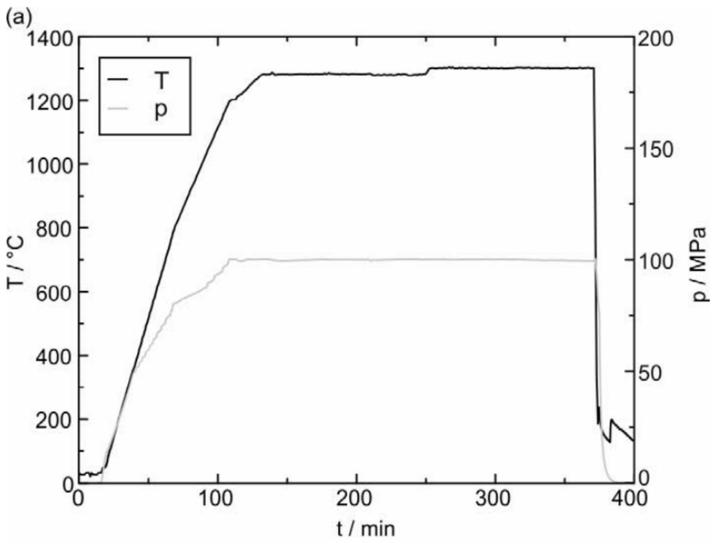
Source: B. Ruttert, Univ. Bochum

Modern HIP equipment

- Enabler for new and innovative cycles tailored for AM
  - Precisley controlled heating, holding plateaus and cooling steps possible

- Heat treatments to be integrated into the HIP process
  - Stress relief, HIP, solution annealing, and aging possible **<u>in one process step</u>**!

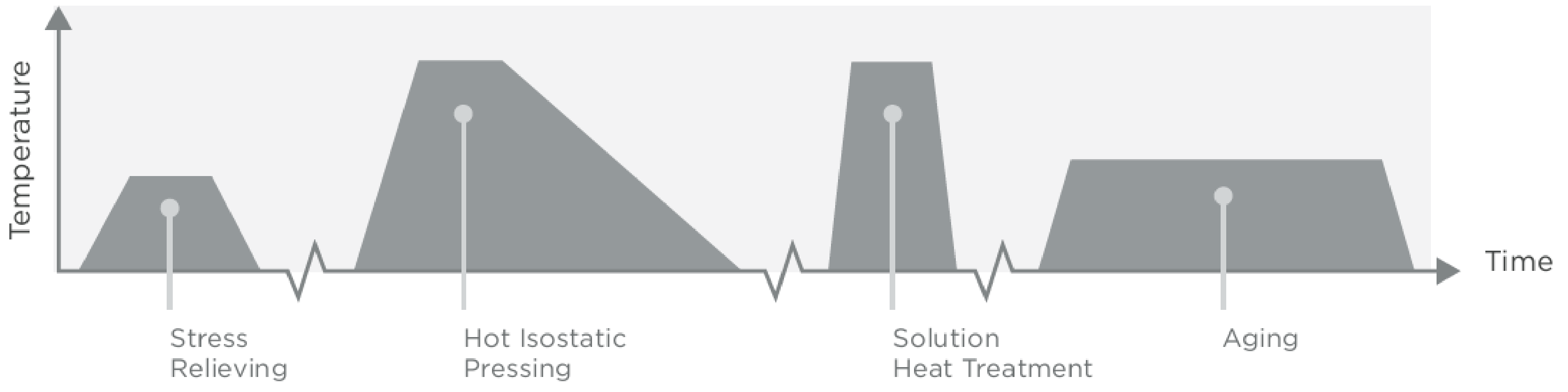




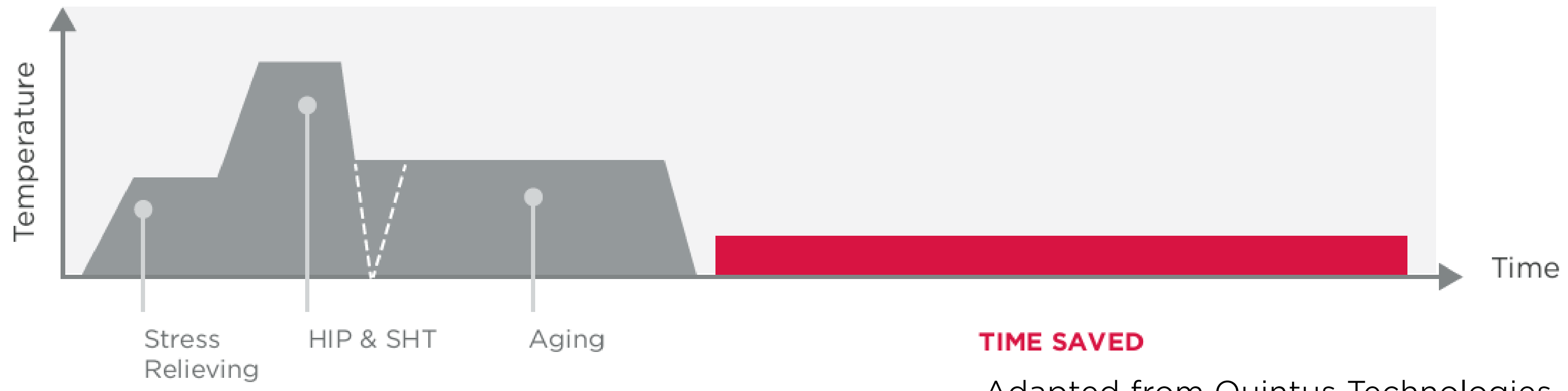
Source: B. Ruttert, Univ. Bochum

Modern HIP equipment for tailored AM HIP cycles

Conventional route



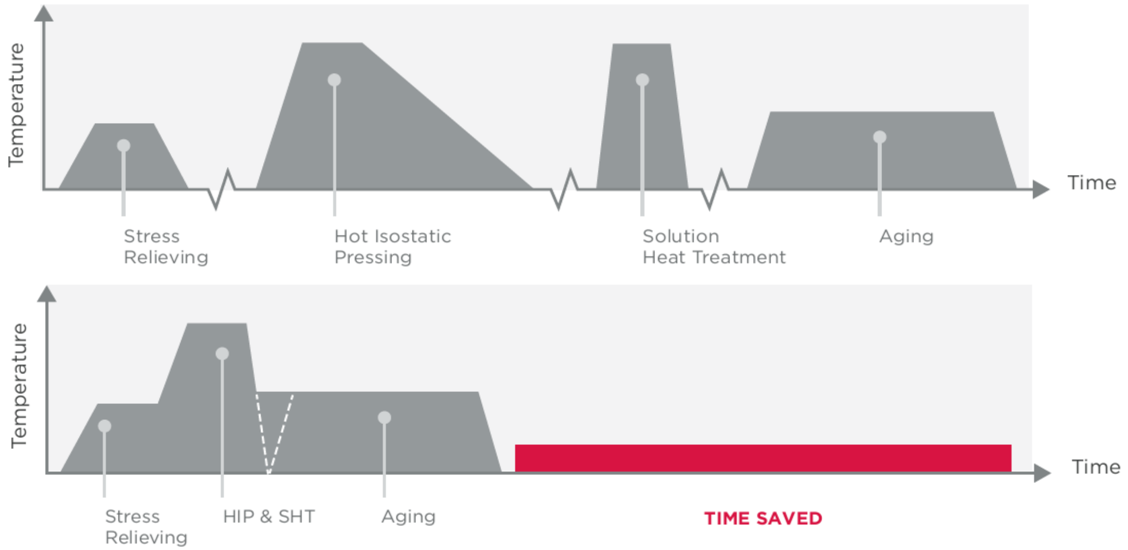
Heat treatments in the HIP



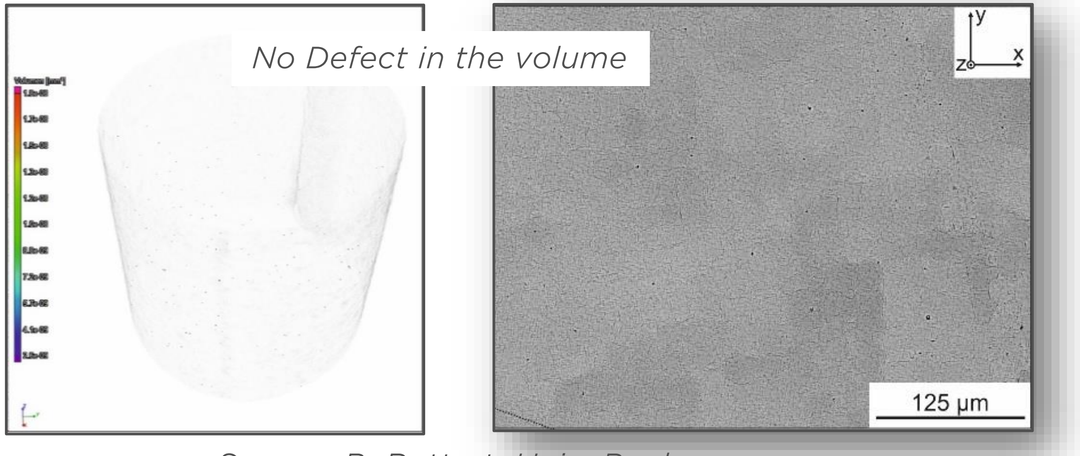
Adapted from Quintus Technologies

Conclusions HIP & AM

- Reduced
  - number of process steps
  - total cycle time, down time, and lead time
  - time at elevated temperature
- Improved
  - process control
  - quality control
  - properties (virtually defect free parts)
- **Results in savings in**
  - **lead time**
  - **reduction in working capital**
  - **energy consumption**



Adapted from Quintus Technologies



Source: B. Ruttert, Univ. Bochum

Summary

Summary

- Hot Isostatic Pressing (HIP) is a special process that removes internal defects
- High temperature (1300°C) and isostatic pressure (207 MPa) simultaneously
- Heat-treatment (stress relief + annealing) and HIP in one proecessing step
- Mechanical properties and corrosion resistance benefit
  - Especially fatigue performance of HIP treated parts benefits significantly

When it Works

- Diffusion Bonding
- Powder densification
- Healing internal defects like porosity or cracks

When it Doesn’t

- Defects that are exposed to the surface
- Surface is not gas-tight (not an issue for castings)
- Repairing defects via HIP in some inexpensive materials may not be cost effective

Questions?

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