

Latest Capabilities in Hot Isostatic Pressing for Advanced Ceramics

Ceramic Expo 2026

Huntington Convention Center of Cleveland, Ohio, USA

Wednesday, May 6, 2026

11:30am EST

Chad Beamer- Applications Engineering Manager
Quintus Technologies LLC

Anders Magnusson – Business Development Manager
Quintus Technologies AB

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Presentation Outline

Agenda

- Introduction to Hot Isostatic Pressing (HIP)
- Advanced Ceramics and Applications in Focus
- Why HIP ceramics?
- Novel HIP Technologies for Advanced Ceramics
- Summary and Q&A

Today's speaker

Chad Beamer

Quintus Technologies LLC
Applications Engineering Manager
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Tel : 614 404 3982

Industry Background:

- GE Aviation: Material Application Engineer
- Bodycote: Technical Services Manager

Academic Background:

- University of Cincinnati: BS in Material Engineering
- Ohio State University: MS in Material Science

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Global leader in high pressure technology

	Quintus Isostatic Pressing			Sheet forming
Product	**Hot isostatic presses (HIP)**	**Warm isostatic presses (WIP)**	**Cold isostatic presses (CIP)**	**High pressure warm forming press (SMFP)**
				
Typical Temperature & Pressure	2000 °C & 200 MPa	145 °C & 600 MPa	25 °C & 600 MPa	270 °C & 140 MPa
Services	Quintus® Care Application Support & Productivity Assurance			
Application Centers	Research & Development Support			

Trivia: *Bottom pressure in the Mariana trench: 110 MPa*

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HIP Application Center – Columbus, OH



Isostatic Pressing Application Center

In-house application R&D

Gain knowledge about equipment in operation

Training and education on the equipment

R&D collaborations globally

Services include:

- Evaluation of new CIP/HIP processes/ applications
- Optimization of current CIP - Sintering - HIP processing
- Proof of concept for potential customers

Application Centers available also in Europe (Sweden) and Asia (Japan)

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Main applications for Hot Isostatic Pressing

Densification of Products

Improve quality for castings, additive manufacturing, and sintered materials





200 MPa (30,000 psi)
2000 °C (3632 °F)
Max diameter x height (Graphite Furnace) 25” x 57” – QIH122
Argon or Nitrogen atmosphere

Diffusion Bonding

To join similar or dissimilar materials together in the solid state. Solid to solid, Powder to solid or powder to powder



Courtesy of MTC Japan

Consolidation of Powder

Near-Net-Shape components or billets of stainless steels, tool steels, HSS, ceramics, etc



Courtesy of Bodycote

High Pressure Heat Treatment

To combine HIP and Heat Treatment cycles to improve product properties and reduce lead time



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HIP Fundamentals

CIP to 600 MPa
HIP to 200 MPa @ 2000°C

HIP Definition:

“Applying an isostatic pressure, distinctly higher than the yield strength of the material at the HIP temperature”

Isostatic pressure?:

- Forming process that applies equal pressure in all directions on a product, compacting the workpiece uniformly from all sides
- Pressure must be applied with a fluid
- HIP: inert gas as pressure medium

Parameters:

- Temperatures are usually 500-2,000ºC (932-3,632ºF)
  - ~80% of materials solidus temperature
- Pressures are usually 100-200 MPa (15,000 to 30,000 psi)

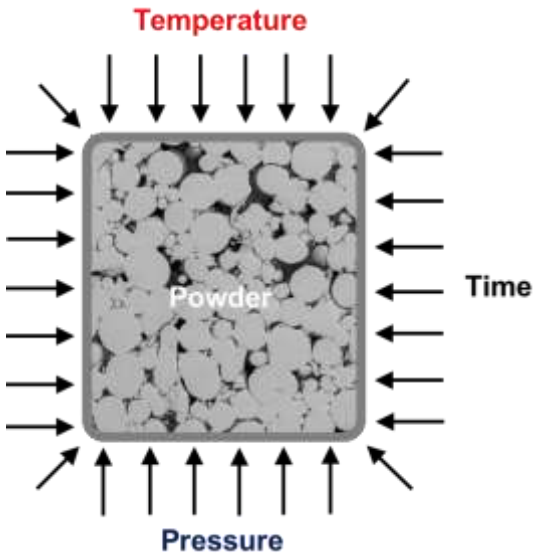
Why?:

- Densification of Solids - elimination of internal defects
- Consolidation of Powder – densify encapsulated powder

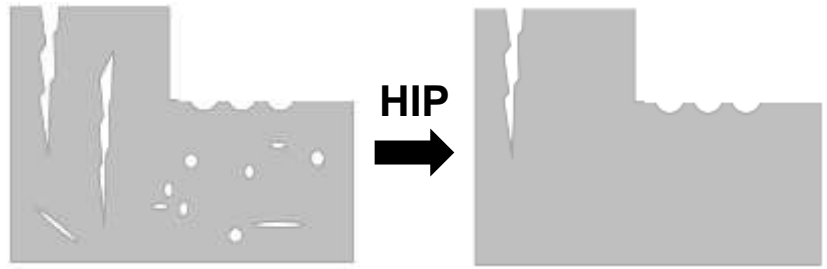
Densification Mechanisms:

1. Mechanical deformation – internal defects begin to collapse
2. Creep
3. Diffusion

] bonding of the collapsed defect



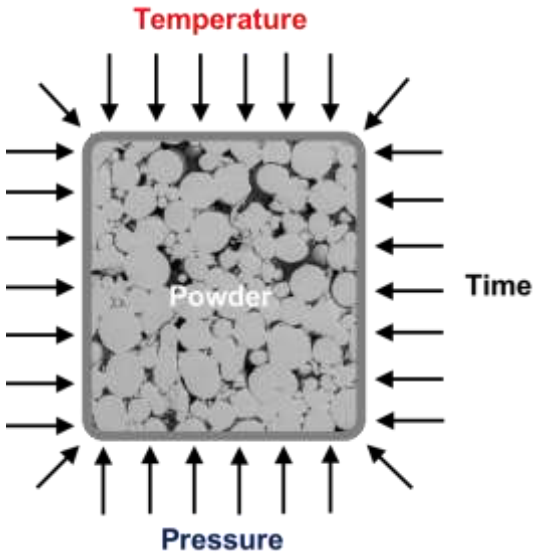
Defect elimination in solids



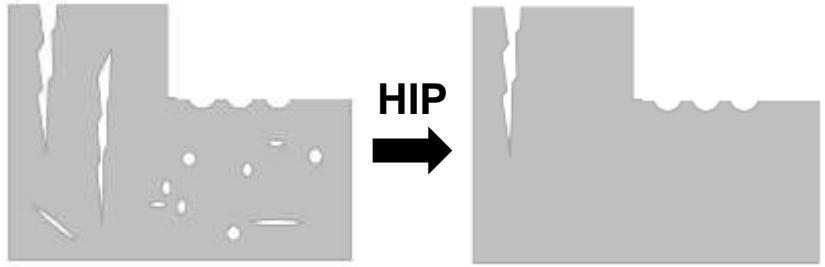
HIP Fundamentals: Process Chain

- Powder preparation
  - Particle size and distribution, sintering aids, composite or grain boundary phases
- **Shaping of green body**
  - **Binder volume and distribution, particle agglomeration, final green density,(cast, CIP, etc), green machining**
- Thermal de-binding (grey body)
  - Vacuum, hydrogen or air atmosphere
- Sintering to minimum a gas tight state (generally to >93-95% of TD)
  - Vacuum or atmospheric pressure
  - Liquid, gas, solid state, reaction sintering
- **HIP to near full density using Temperature, Pressure and Time**
  - 1400°C (nm grainsize Alumina) - 2000°C (low sintering aid SiC)
- Finishing, surface grinding and polishing
  - Surface defects are the main strength and reliability limiting factor for brittle materials

CIP to 600 MPa
HIP to 200 MPa @ 2000°C



Defect elimination in solids



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The world is waking up to the possibilities with advanced ceramics

Application:
NASA space shuttle program had the need to find a bearing for a **turbo pump** that could take >30kRPM **pumping liquid oxygen fuel** for a total of **55 flights minimum**



Note:
Also ceramic implant manufacturers uses this method of convincing, dropping hip balls from high buildings hitting the stone pavement, hip ball bouncing away without fracturing!!

Drastic way to convince the organization that not all ceramics are brittle and unreliable....

High end applications in Focus for HIP

Ceramic bearings and seals

Silicon Nitride, SiC

- Low density, low inertia
- No electrical and low chemical corrosion
- Tolerant for lubricant starvation
- Crush hard contaminants

Medical implants

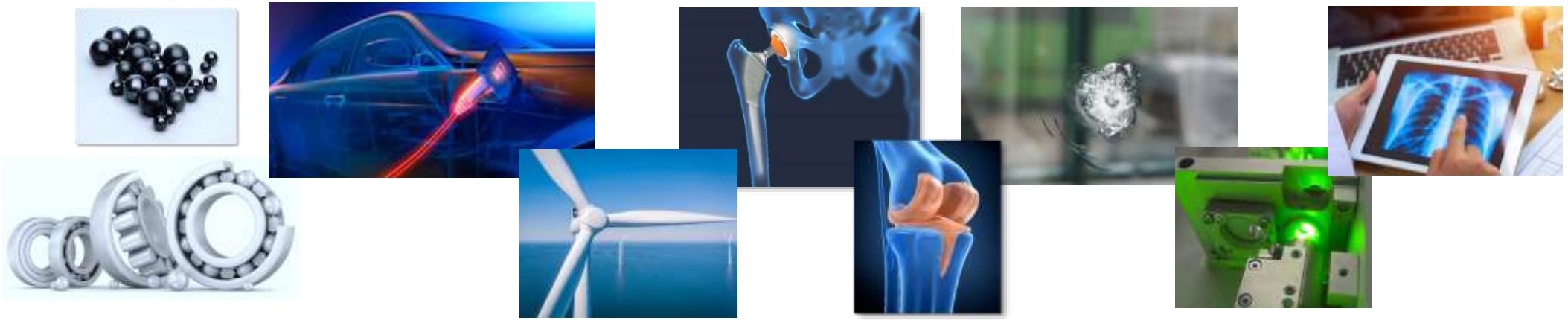
ZTA, ATZ, SN, Alumina

- Superior wear resistance
- Best biocompatibility
- Lowest chemical degradation and loss of particles

Optical applications

Spinel, AlON, YAG

- High hardness, toughness, low density
- Transparent, translucent
- Possible to dope for scintillation

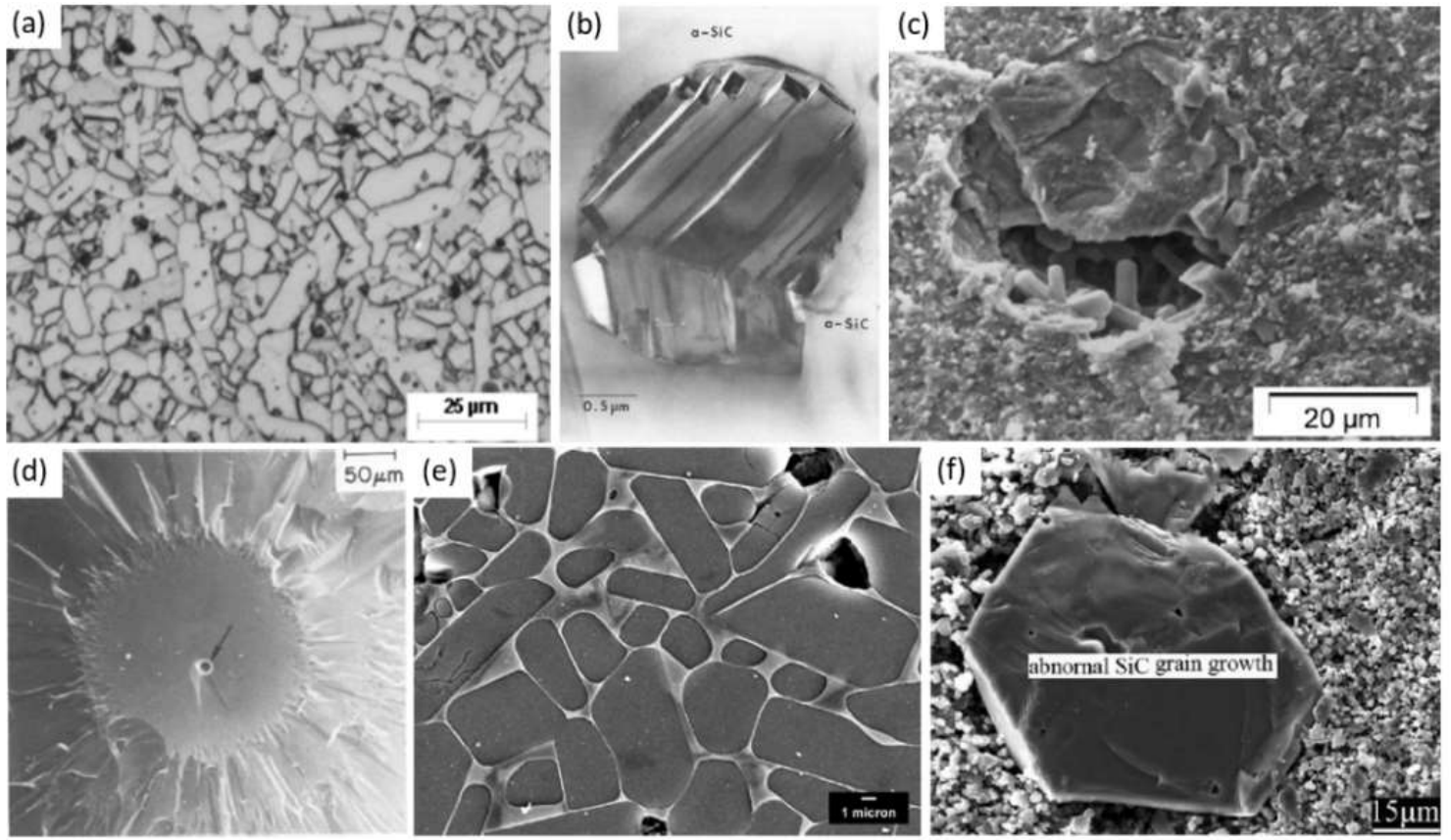


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Why HIP for Ceramics?

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Defects to be combated to achieve strength and reliability



Dargaud, PhD thesis (2021)

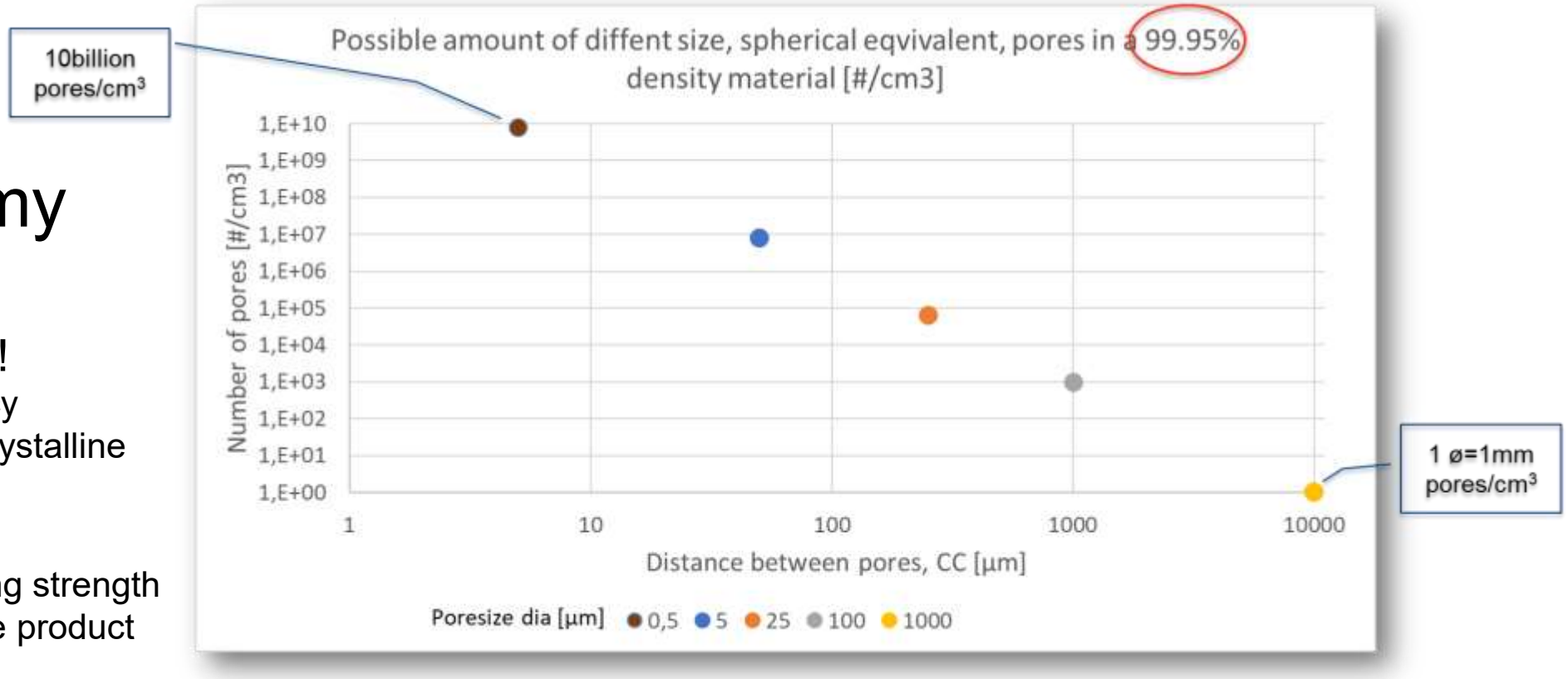
Eliminate or minimize pores, void, cracks….and do so without excessive temperature

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Pores and voids: The basic case for isostatic pressing

Sintering alone my not be sufficient:

- 10 billion pores/cm^3!
  - Making transparency impossible in polycrystalline materials
- 1mm pore/cm^3!
  - Large pore impacting strength and reliability for the product



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HIP for high strength advanced ceramics

- $G = \sigma^2 \pi a / E \geq G_c = 2 \gamma$ (Griffith)
- $K = \sigma \sqrt{\pi} \sqrt{a} \geq K_c$ and $G_c = \sigma^2 \pi a / E = K_c^2/E$ (Irwin)
- $rp = (K_c^2/\sigma_Y^2)(1/\pi)$ (radius of plastic zone at crack tip)
- $\sigma_0 \sim 1/\sqrt{D_{grain}}$ (Hall-Petch)

Key equations for fracture mechanics and crack propagation



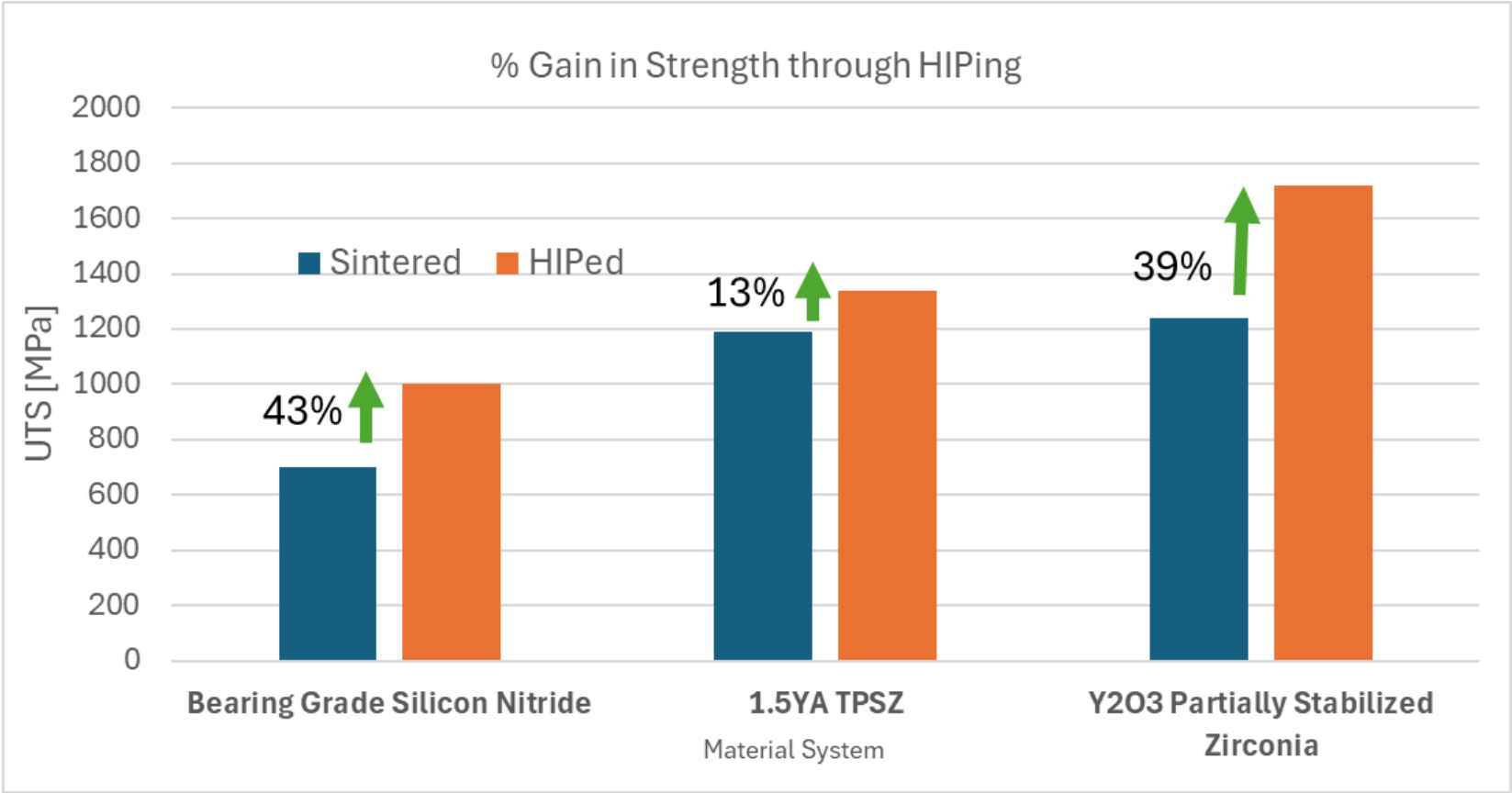
Critical defect size in low micron range

Critical defect size for ceramics 1/1000 of ductile metals!

Flaw size dominates the failure mechanism: Pores, cracks, voids, and large grains: All considered “defects” when it comes to UTS (Ultimate Tensile Strength)….

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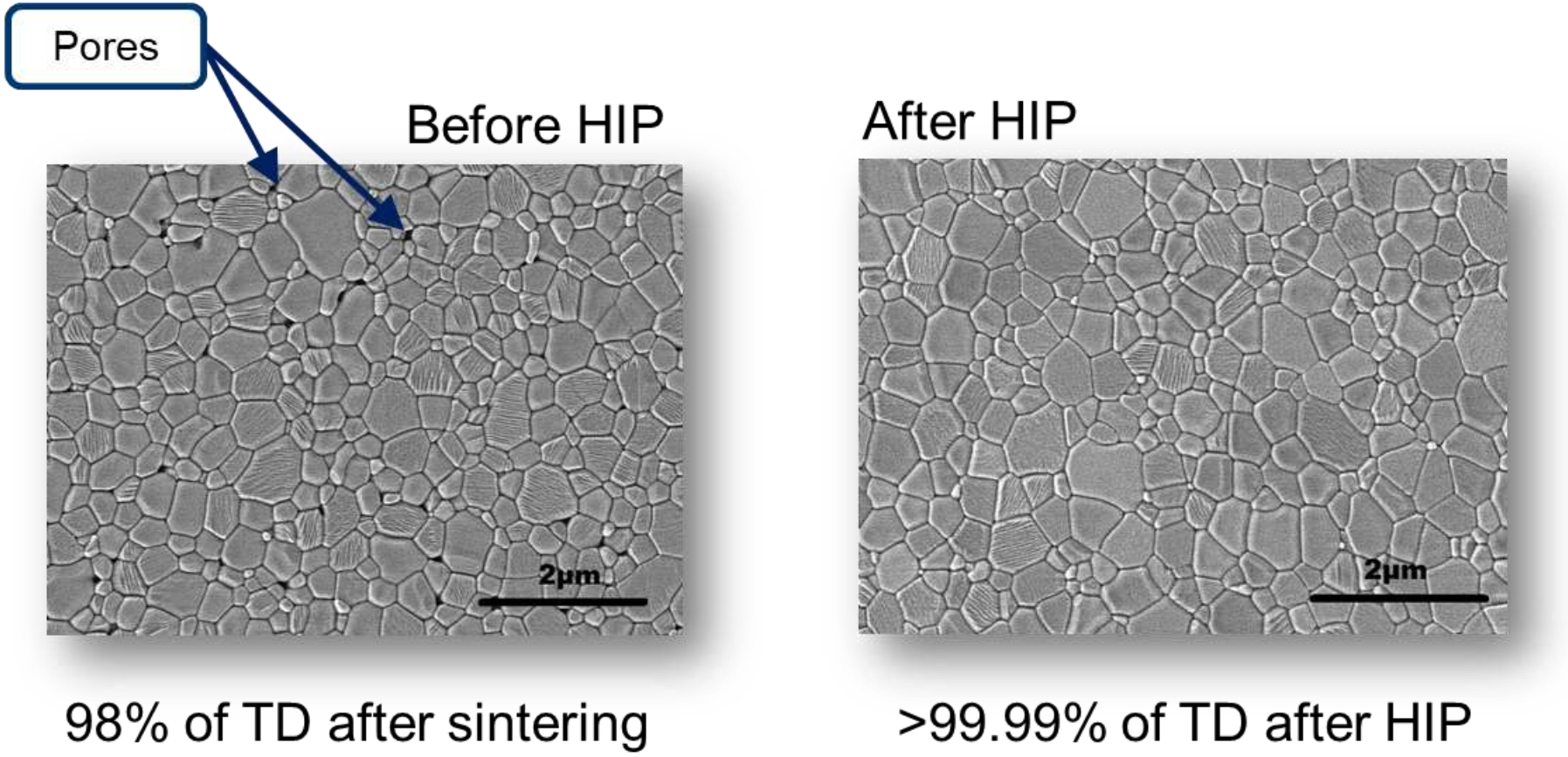
Strength and reliability increase from HIP densification



Courtesy of:
HIP Silicon Nitride VS GPS Silicon Nitride-TECHNICAL-Sinoma Advanced Nitride Ceramics Co., Ltd. (sinomanitride.com)
Matsui et al, Ultrahigh toughness polycrystalline ceramics without fading of strength, 2021
Ceramic Material Properties - 01042R (coorstek.com)

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HIP allows for densification with minimal grain growth



Sintered (a) alumina made transparent (b) by HIP densifying remaining pores
while retaining submicron grain size (Courtesy of **POLYCRYSTAL design GmbH, Lithoz GmbH and Quintus Technologies AB**)

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HIP enables transparency for non-cubic PX-alumina!

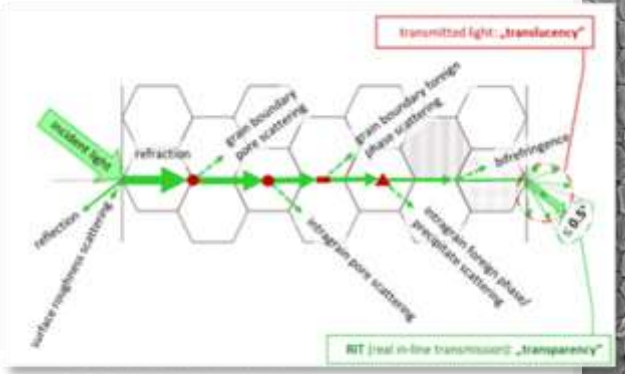
Best example for achieving full densification at minimal grain growth

High pore density, gives a milky white component

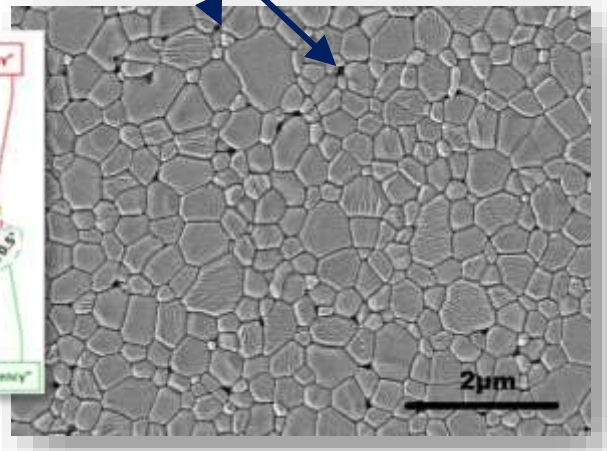




After HIP, >99.99% of TD gives transparency (t<1mm)



© Quintus Technologies



Before HIP, 99% of TD

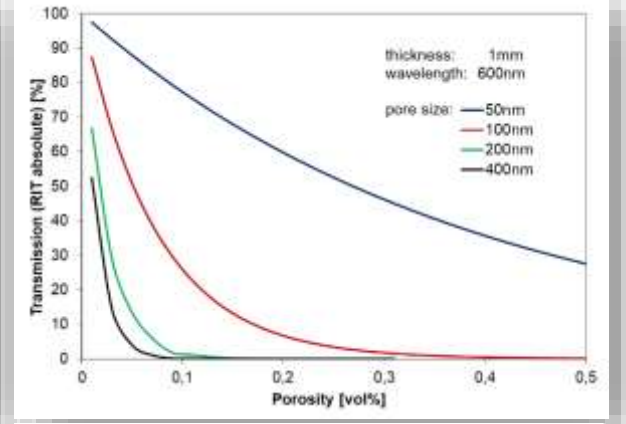
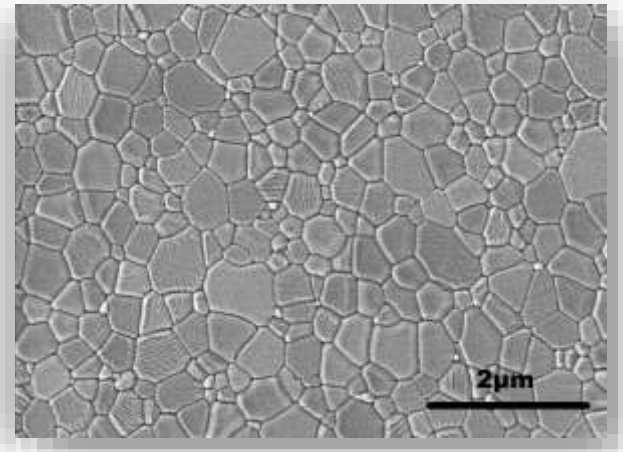


Figure 2 Mie-scattering calculation of transmission loss due to porosity for alumina ceramics (without reflection and birefringence) [J. Klimke, POLYCRYSTAL design]



Sintered alumina plates made transparent using high pressure, low temperature HIP, densifying remaining pores while retaining submicron grain size (Courtesy of POLYCRYSTAL design GmbH and Lithoz GmbH)

POLYCRYSTAL LITHOZ CERAMICS EXPO Quintus TECHNOLOGIES

The HIP operating cost – calculation case

Quintus QIH48



- Operating cost of HIPing consists of:
  - Electricity, Process gas (Argon), Man hours, Maintenance and service
- Calculation case:
  - Part: HIP ball head, 30 mm diameter
  - Material: ZTA / ATZ
  - HIP cycle: 1500 °C, 150 MPa, 2 h soak, 18 K/min controlled cooling ➔ 7.5 h total cycle time
  - HIP system evaluated: Quintus QIH48 G URC® , Ø = 350 mm, h = 1100 mm

HIP ball head



Assumed cost for utilities (Europe)	
Electricity	0.25 EUR/kWh
Argon	1.25 EUR/Nm^3
Labor	40 EUR / man hour
Maintenance and service	Quintus Care program

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The HIP operating cost – calculation case

- Loading capacity
  - 90 parts / level and 26 load levels = 2340 parts / cycle
- Production capacity:
  - Production conditions: 16h, 5 days/week, 48 weeks/year, 95% uptime
  - ➔ 456 cycles / year ≈ 1.07 million parts / year
- The calculated HIP operating cost = 0.22 EUR / part
  - No contact between parts is conservative
  - Free loading of parts in contact (60% fill grade) ➔ 4080 parts / cycle ➔ 0.16 EUR/part

Consumptions for HIP cycle	
Electricity	390 kWh (0.16 kWh/part)
Argon gas	12 Nm^3
Labor (separated)	5 hours
Maintenance and service	Quintus Care program

With gas reclaim functionality ~90% for lower gas consumption

Including loading of parts into the load baskets

Example: loading of parts in graphite load basket, no contact between parts

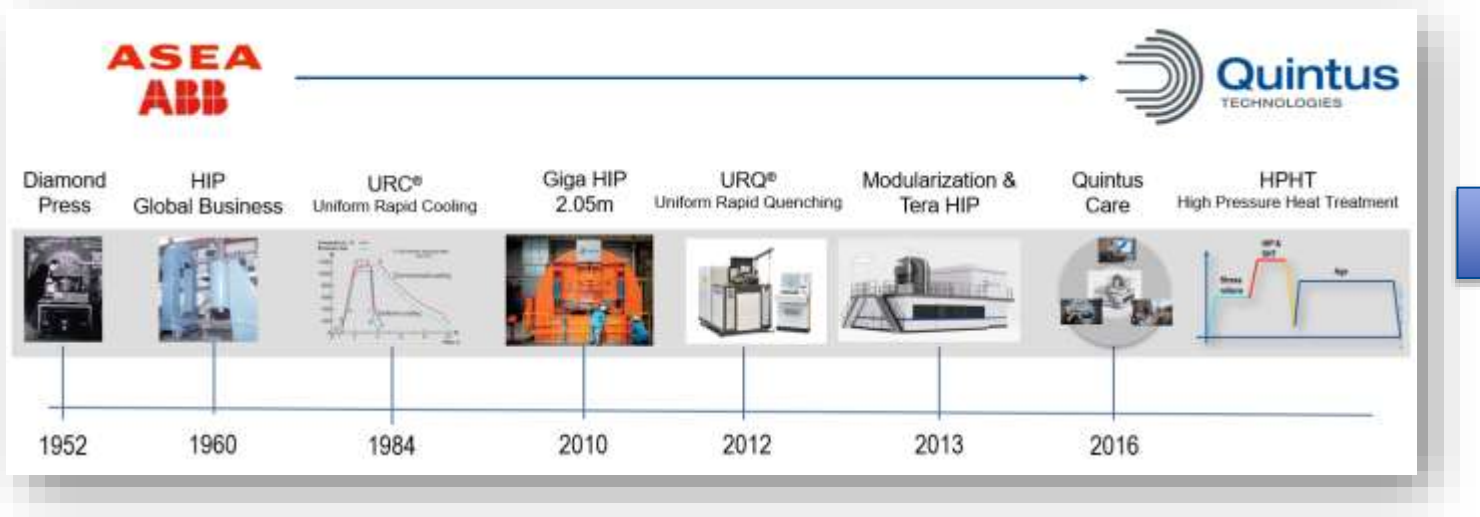


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State-of-the-art HIP Equipment

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Evolution of capabilities, use for Advanced Ceramics



- HIP processing knowledge
- Unique equipment capabilities

HPHT
High Pressure Heat Treatment

- **URC®,** Uniform Rapid Cooling, for controlled, increasing of productivity
- **URQ®,** Uniform Rapid Quenching, for “quenchable” material systems
- **Steered Cooling™**
  - Controlled cooling segment rate and time
  - Controlled temperature stresses in brittle materials
- **Quintus PURUS®,** controlled surface properties

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Quintus offers new possibilities, also for Ceramics

Clean process atmosphere with Quintus Purus®

- Avoid surface dissociation, corrosion and carbonization without using a powder bed
- Keep the HIP system clean
- Prolong HIP furnace life minimizing oxidation and evaporation of heating elements, load baskets, etc.

Take control of the process using Steered Heating and Cooling™

- Improve productivity and quality
  - Optimize and set a reproducible process cycle
- Retain / modify crystal structures and grain boundary phases using a tailored cooling rate utilizing the compressive stresses from isostatic pressure

Stack parts on parts, maximizing use of furnace volume

- Utilizing the combination of low material density, high gas pressure contact points and the buoyancy effect
- Ar >400g/dm3 at std ceramics process temps and pressures

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Quintus ongoing project on advancing ceramics

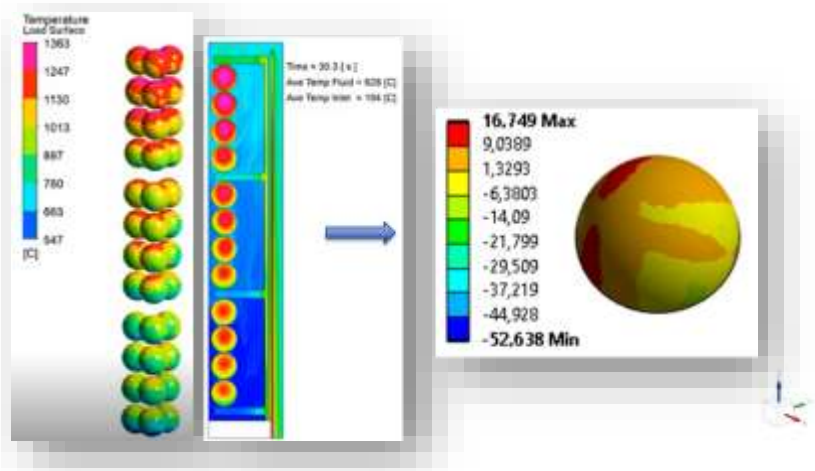
1. Steered cooling™ for productivity, resource efficiency and more...
   - Combined with stacking for x6 productivity
   - Explore phase transformations, precipitates and diffusivity also for brittle systems

2. Clean HIPing with Purus® features for ceramics and graphite furnace
   - Avoid condensation evaporates, and carbon contamination with product surface to improve transparency in PX ceramics





Several R&D initiatives evaluating Quintus Purus® to improve transparency in PX ceramics





Consumptions for HIP cycle	
Electricity	390 kWh (0.16 kWh/part)
Argon gas	12 Nm³
Labor (separated)	5 hours
Maintenance and service	Quintus Care program

With gas reclaim functionality ~90% for lower gas consumption

Including loading of parts into the load baskets

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Summary and Conclusions

- HIP can take your material system from good to great (Isostatic Pressing Basics)

- New HIP capabilities being explored for Advanced Ceramics
  - **Quintus Purus®** - HIP'ing with a clean atmosphere
    - Potential to reduce defects in Si3N4 HIP processing
    - Benefits for maintaining transparency in non-cubic polycrystalline alumina
  - **URC® and Steered Cooling**
    - Productivity benefits in the medical industry for ZTA
    - Potential to mitigate "snowflake" defects in Si3N4
    - Ability to steer cooling rates to resulting end microstructure



HIP Application Center – Columbus, OH



Isostatic Pressing Application Center

In-house application R&D

Gain knowledge about equipment in operation

Training and education on the equipment

R&D collaborations globally

Services include:

- Evaluation of new CIP/HIP processes/ applications
- Optimization of current CIP - Sintering - HIP processing
- Proof of concept for potential customers

Application Centers available also in Europe (Sweden) and Asia (Japan)

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Thank you for your attention! Time for Q&A



Visit our
Knowledge Center

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Case Studies

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Quintus HIP and URC® for high performance SN products

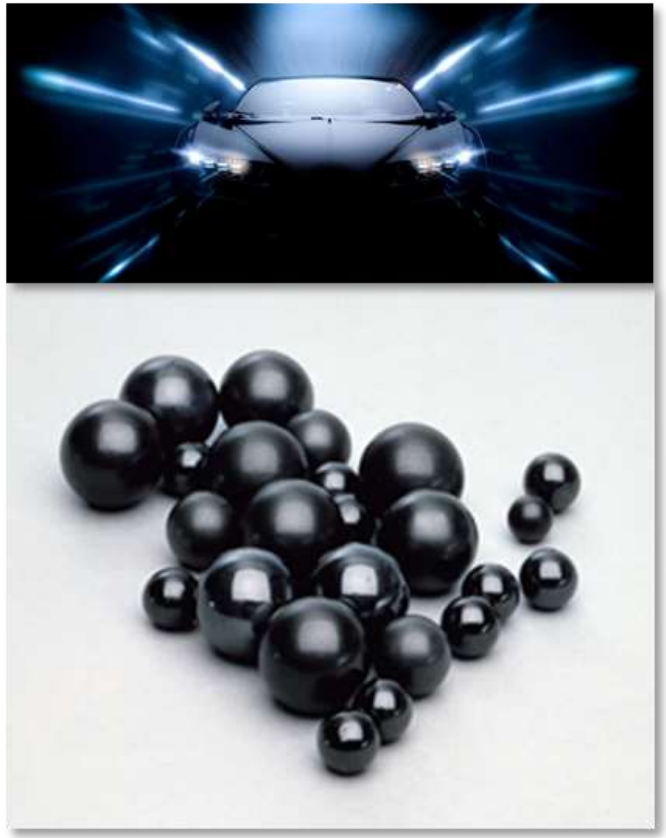
Optimal combination for high performance HIPSN products

Enables:

- **HIP:** Densification of even micrometer size pores and voids to achieve maximum component strength, toughness and reliability
- Tailoring of grain boundaries to meet requirements for intended use of product

*Prevent*s:

- Nitride dissociation and SiO(g) evaporation from product surfaces by controlled process atmosphere with **Quintus Purus**
- “Snowflake" defects formation to reduce costly surface grinding with **URC/Steered Cooling**

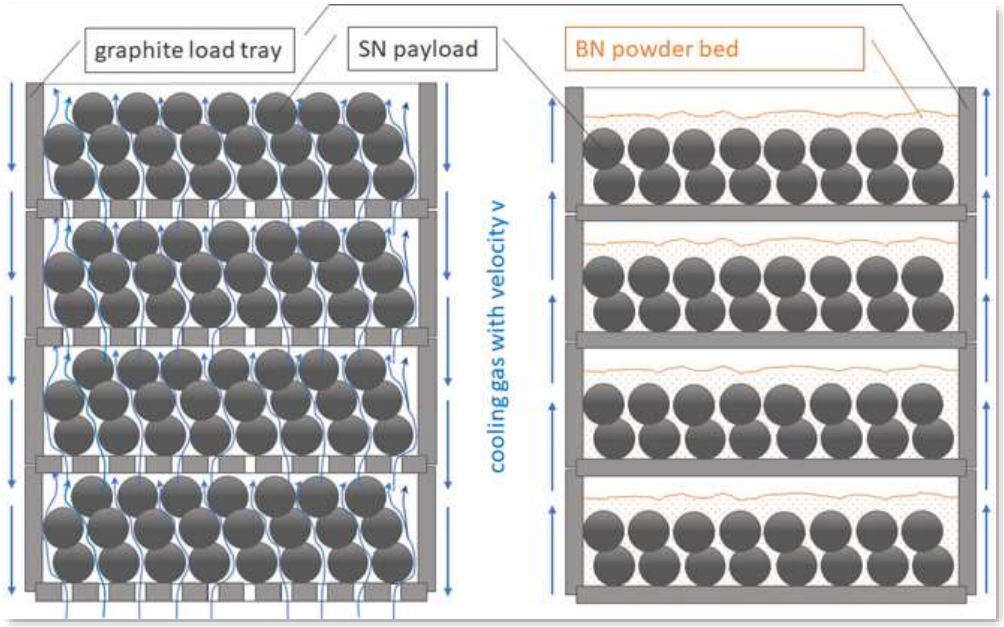


[9]P. Uyan et.al., “Effect of Cooling Cycle after Sintering on the Thermal Diffusivity of Y2O3 Doped Si3N4 Ceramics”; Universal Journal of Materials Science 6(1): 39-47, DOI: 10.13189/ujms.2018.060105 (2018)
[10]M. Jasch,

Powder bed free HIPSN operation

Powder bed free operation enables URC ® and Quintus Purus operation

- Increase HIP productivity through soft, steered, uniform rapid cooling, URC®
  - Limit the cooling segment <1h
- Ensure product quality and reduce cost of maintenance from improved HIP hygiene
  - No powder dust deposits in the HIP system



Zirconia Toughened Alumina, ZTA for Longevity

Benefits from using Quintus Technologies HIP for high performance ZTA products

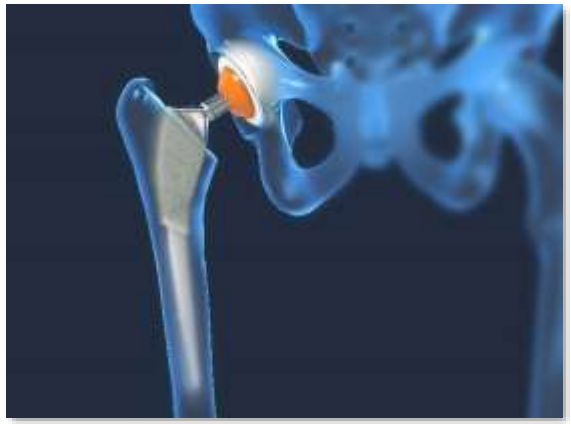


Enables:

- **HIP:** Densification of even micrometer size pores and voids to achieve maximum component strength and reliability
- Increase HIP productivity through soft, steered, rapid cooling, **URC/Steered Cooling** , to minimize the cooling segment to be <1h

Prevents:

- Unwanted phase transformations or grain growth by simultaneous controlling and steering of all influencing process parameters: isostatic pressure, temperatures and cooling rates



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Novel capability #1: Quintus Purus®, referred to as Clean HIP Processing

Established for metals, now exploring the benefits for Advanced Ceramics related to greying effect on samples



Quintus Technologies: c-ZrO2 before and after graphite HIP

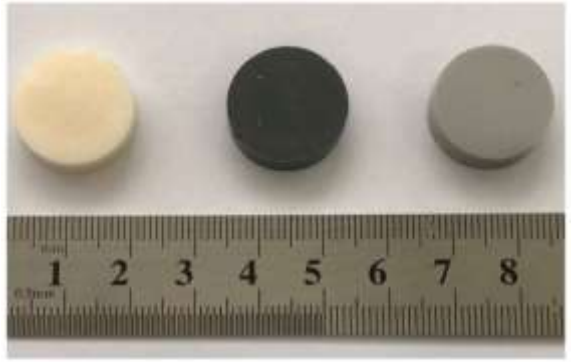


FIGURE 1 Alumina specimens sintered at 1600°C for 2 h in an air furnace (white in color) and a graphite furnace with flowing He (black). The specimen that was air fired at 850°C in air and sintered in the graphite furnace at 1600°C is gray in color. The different colors are due to different carbon contents in the specimens originating from the binder in the ready-to-press powder [Color figure can be viewed at wileyonlinelibrary.com]

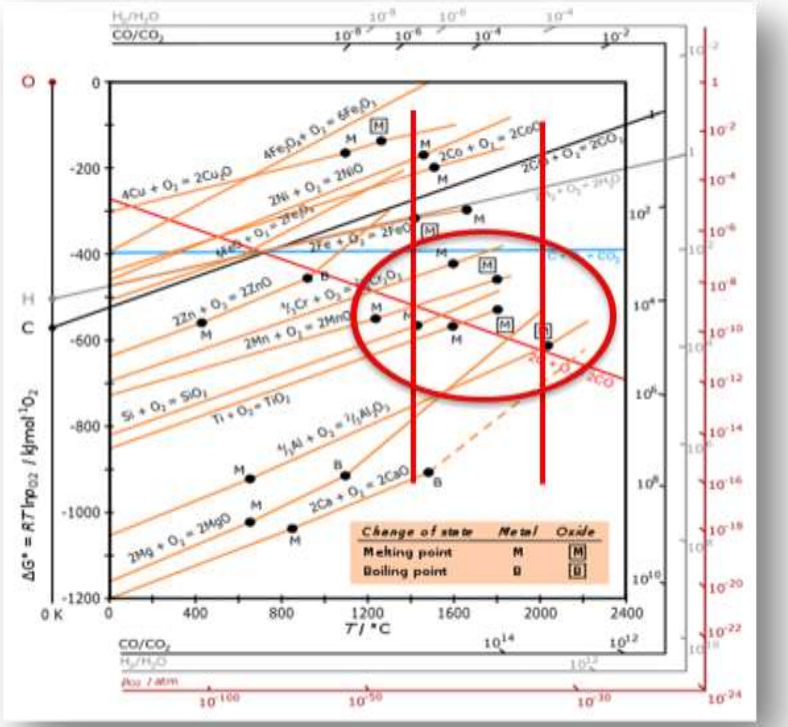
Marder et al, *The influence of carbon on the microstructure and wear resistance of alumina, 2019*

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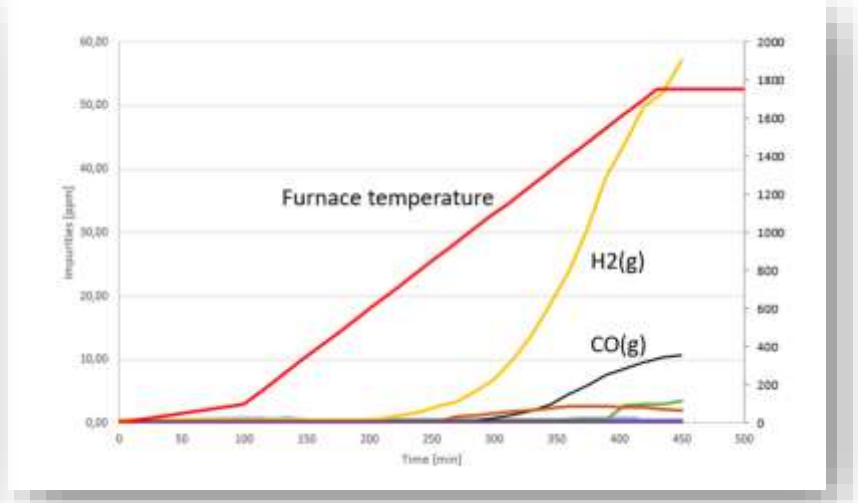
Graphite HIP process atmosphere challenges

Ellingham diagram



- Evolution of CO(g) in HIP furnace
- CO(g) dominates oven the stable oxides ceramic at high temperatures

HIP in-situ gas analysis



- Discloses the reactions and gas evolution in HIP!

Reactions with CO(g) undesirable!

2H2O(g) ⇌ 2H2 (g) + O2 (g)
C(s) + O2 (g) ⇌ 2CO(g)
2C(s) + 3H2 (g) + 2N2 (g) ⇌ C2 N2 (g) + 2NH3 (g)
Evaporation of volatile SiO(g) from the SN surface follows due to oxygen deficiency
Si(g) + SiO2 (s) ⇌ 2SiO(g) and H2 , as released from the water reaction with the graphite heater, reacts strongly with the oxide layer on silicon nitride, and SiO2 in the binder phase, above 1250°C, releasing even more water vapor:
SiO2(s) + H2 (g) ⇌ SiO(g) + H2 O(g) which in turn reacts at high temperatures directly with silicon nitride:
3H2 O(g) + Si3 N4 (s) ⇌ 3SiO(g) + 2N2 (g) + 3H2 (g

- Oxygen species in the process atmosphere can trigger a chain of unwanted reactions

Keeping an inert, low CO(g), HIP process atmosphere

Evaporated species can condensate in a graphite furnace resulting from a high oxygen levels in HIP atmosphere



- C(s) + O(g) -> CO(g) (from O_2 or H_2O)
  - CO(g) + MeOx(s) -> CO2(g) + MeOy(g)
  - CO(g) -> C(s) + CO2(g) (sooting)

Several R&D initiatives evaluating Quintus Purus® to improve transparency in PX ceramics



POLYCRYSTAL

- Path to avoid carbon contamination with product surface!
  - Ruin transparency
  - Require additional air annealing



Target state for transparent ceramics

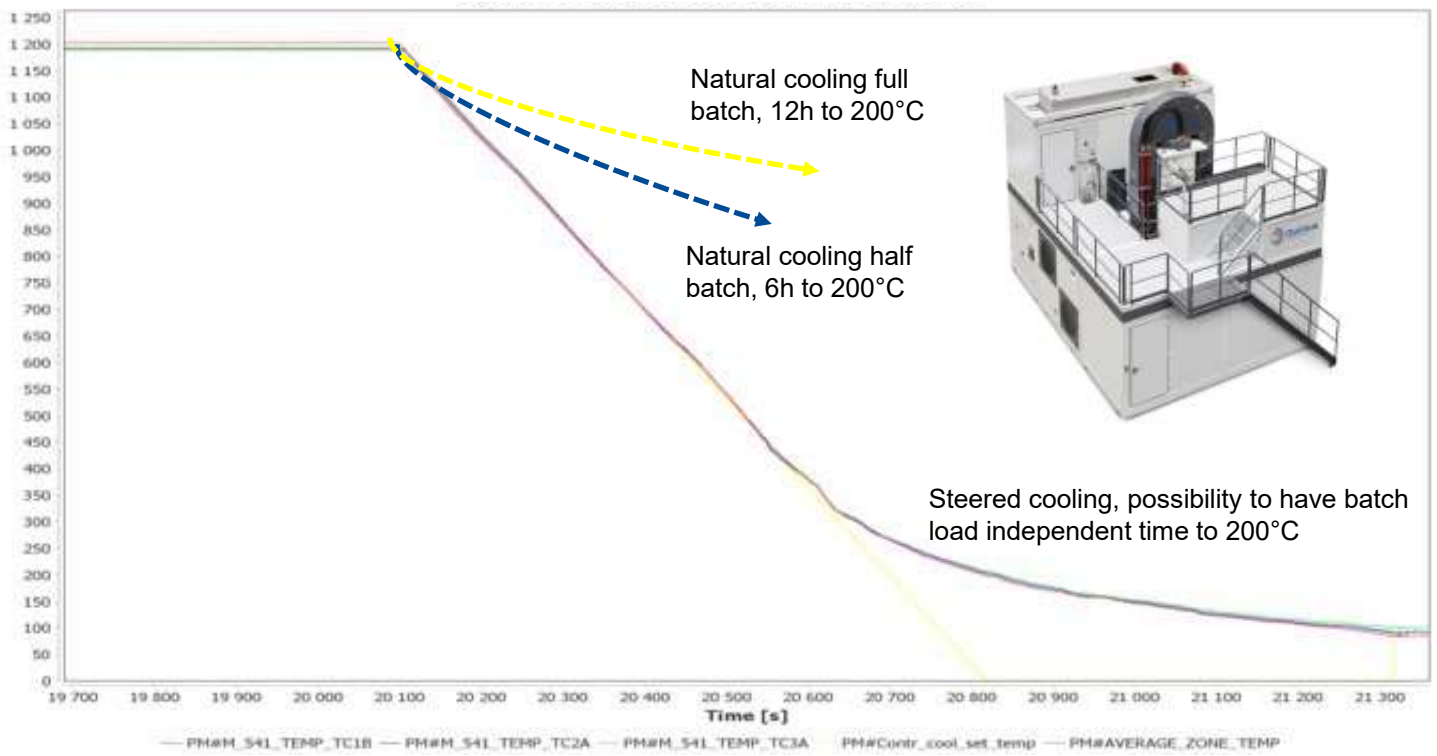
- Maximize in-line transparency
- Maximize possible component thickness
- Optimizing yield and cost of manufacturing

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Novel capability 2: Steered cooling for brittle materials

Steered cooing example 1300kg in QIH122, 100K/min



HIP Steered cooling:

- Uniformity: High density (pressurized) gas gives maximum temperature uniformity throughout the batch
- Process control and repeatability
- Integrity: High isostatic pressure keeps the components in compression

Purpose:

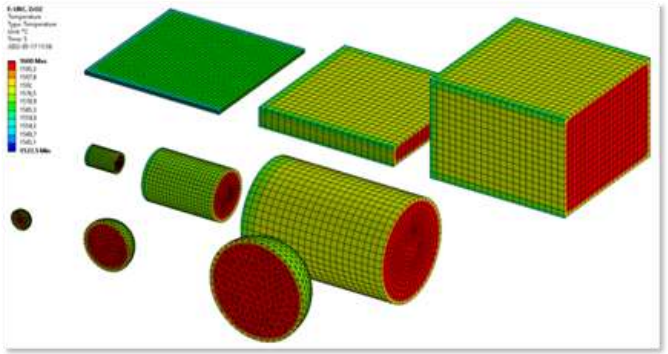
1. Quality
2. Productivity
3. Modify ceramic structure

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Understanding the possibilities and limitations

Find the cooling rate for material and part geometry in hand

- Maintain a compressive state during the entire cooling cycle
- Can be calculated when accounting for heat conductivity and compressive stresses
- Beneficial combination of properties for fast cooling
  - Low thermal expansion coefficient
  - Low wall thickness
  - High thermal conductivity
  - High strength
  - Low Young's modulus
  - No stress concentrations





Note: 1D calculation only for guidance as actual stresses very much dependent on geometry

	Cooling rate, component thickness			
Material	20K/min 5mm [MPa]	20 K/min 50mm [MPa]	70K/min 5mm [MPa]	70 K/min 50mm [MPa]
Si3N4	-75	-50	-10	205
ZTA	-60	-10	95	
Al2O3	-65	-15	80	
ZrO2	15	300		
SiC	-80	-75	-70	-30
ALON	-40	80		
MgAl2O4	-55	25		
AlN	-80	-75	-65	-15

Calculated approximate thermoelastic principal stresses during uniform rapid cooling from 1000°C when retaining 80MPa isostatic pressure until safe unloading temperature (using generic material specific data)

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