TUNGSTEN POWDER INJECTION MOLDING, TUNGSTEN ARMOR, MOCKUP FABRICATION

Karlsruhe Institute of Technology (KIT)
Institute for Applied Materials
Material Process Technology

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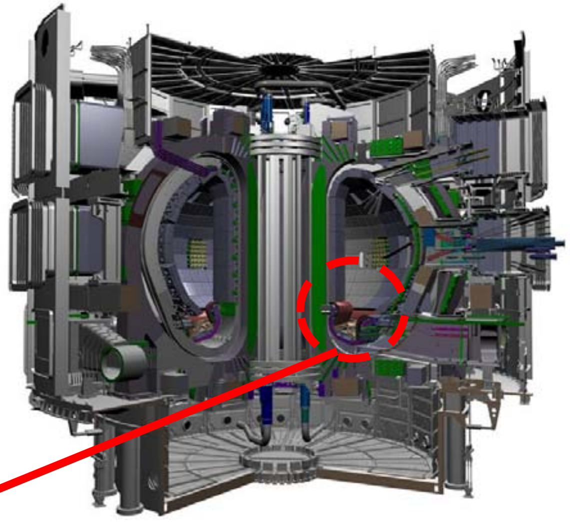
Challenges to Developing W-Based Materials for Fusion Applications
University of California Santa Barbara
February 13 – 15, 2012

Outline

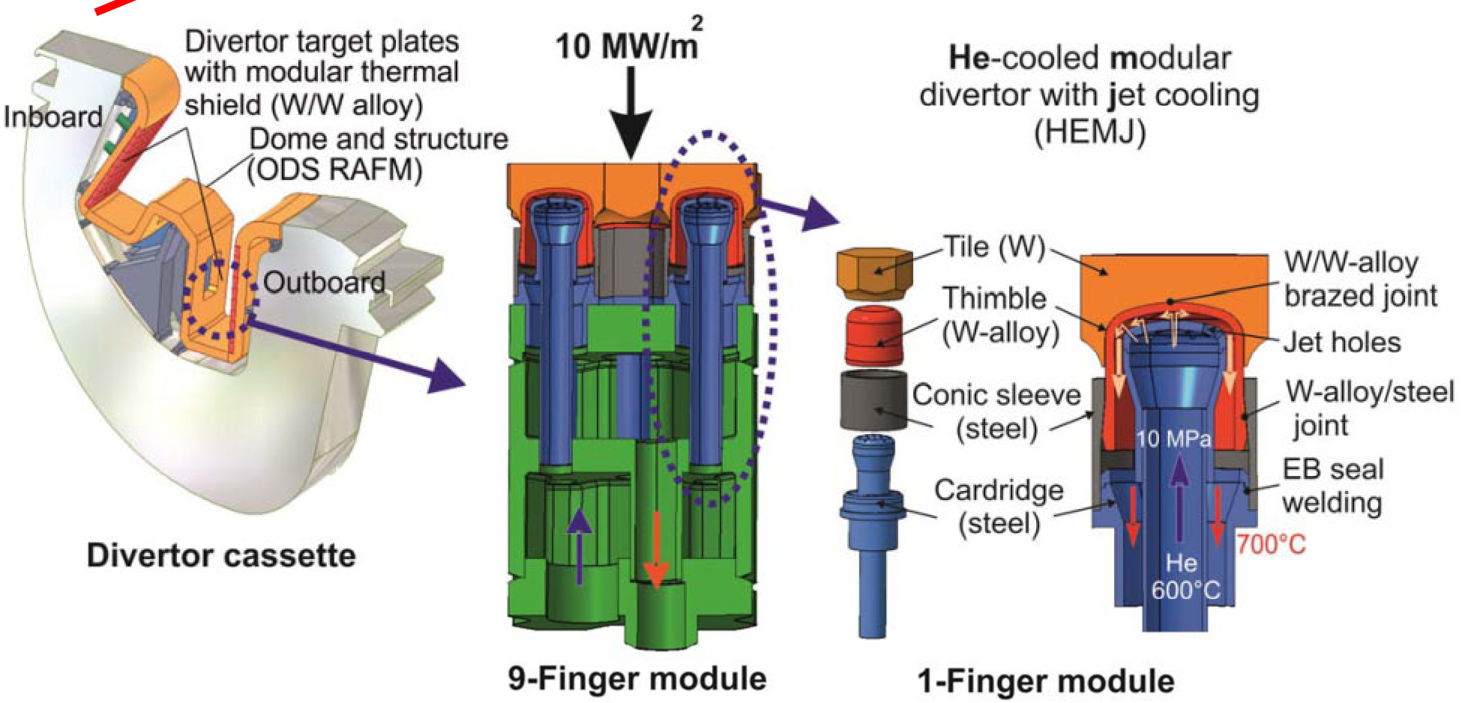
- **Motivation**
- **What is Powder Injection Molding (PIM)?**
- **The PIM process for tungsten developed at KIT**
- **Material development for PIM**
- **2-Component tungsten PIM**
- **Summary & Outlook**

Motivation



Future fusion power reactor DEMO

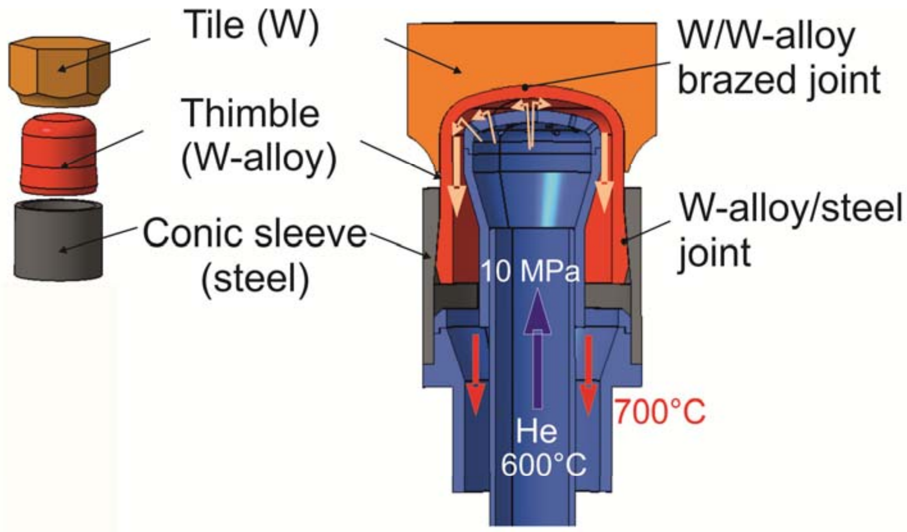
One promising divertor design – developed at KIT



P. Norajitra et al., KIT.

Motivation

⇒ 1 Finger-module – 3 main parts
⇒ 2 – 3 several materials
⇒ 2 brazed joints
⇒ assembling, adjustment…



1-Finger-Mockup

⇒ DEMO: nearly 300.000 mockups
⇒ lifetime nearly 2 years

⇒ **Reasonable manufacturing method?**

What is Powder Injection Molding (PIM)?

PIM – *Powder Injection Molding*: manufacturing technology

→ MIM – *Metal Injection Molding*

→ CIM – *Ceramic Injection Molding*

Advantages

⇒ Cost-effective mass production

⇒ Producing of 3D-parts

⇒ Metal forming of tungsten based materials complicated

Challenges

⇒ Adequate powders / powder mixtures

⇒ preparation / feedstock development

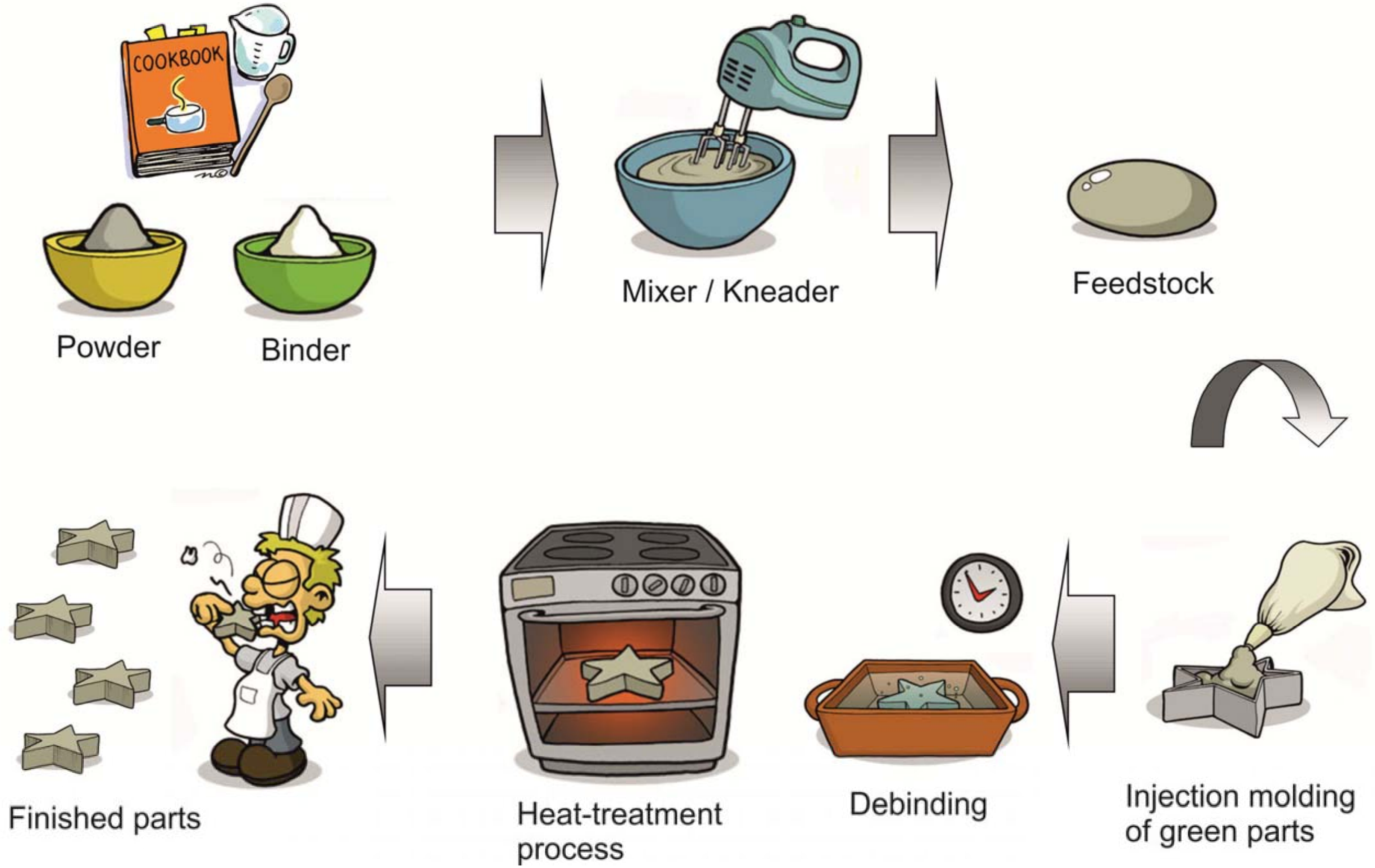
⇒ Heat-treatment process

  ⇒ High density

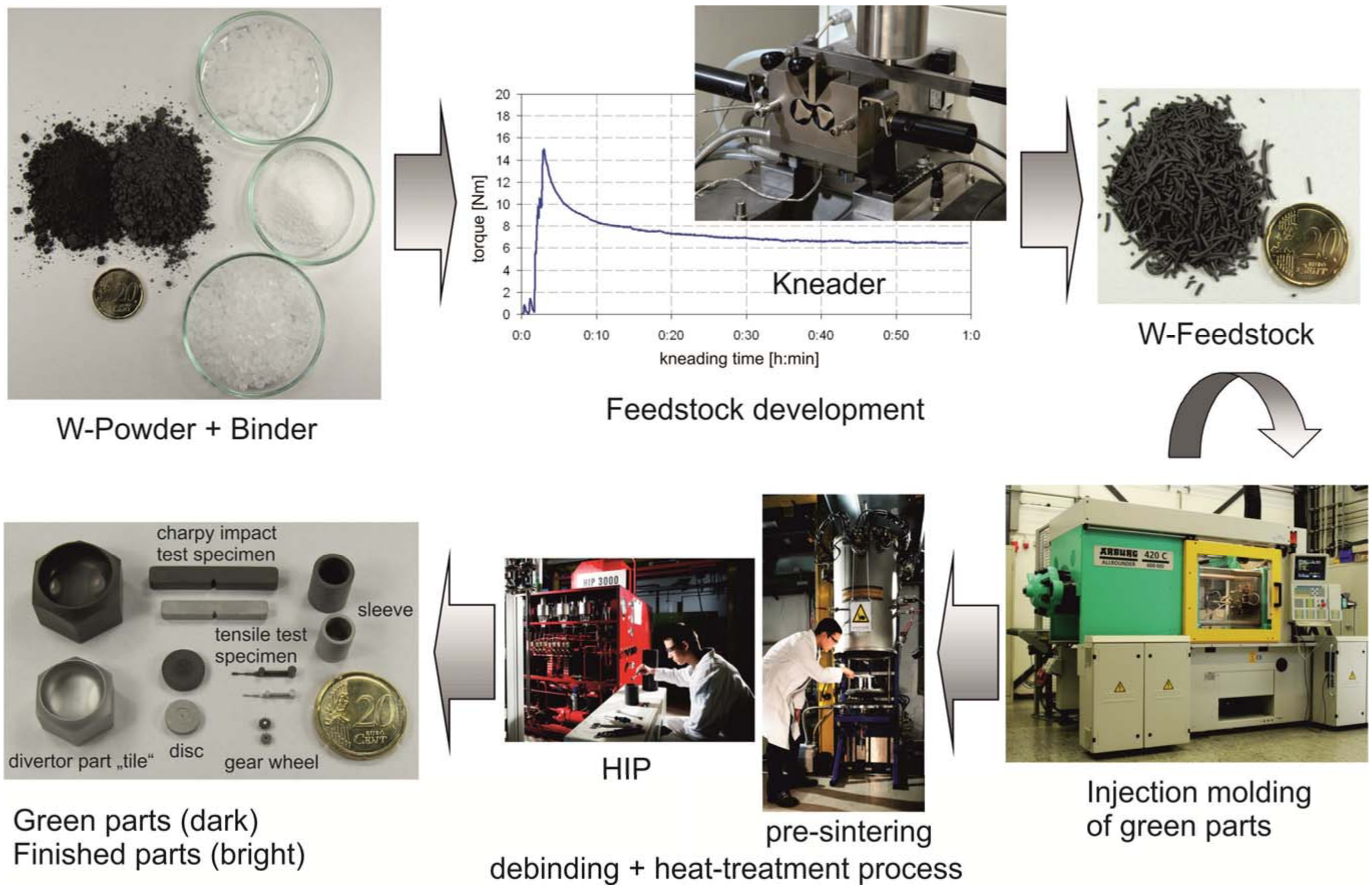
  ⇒ Low porosity

What is Powder Injection Molding (PIM)?

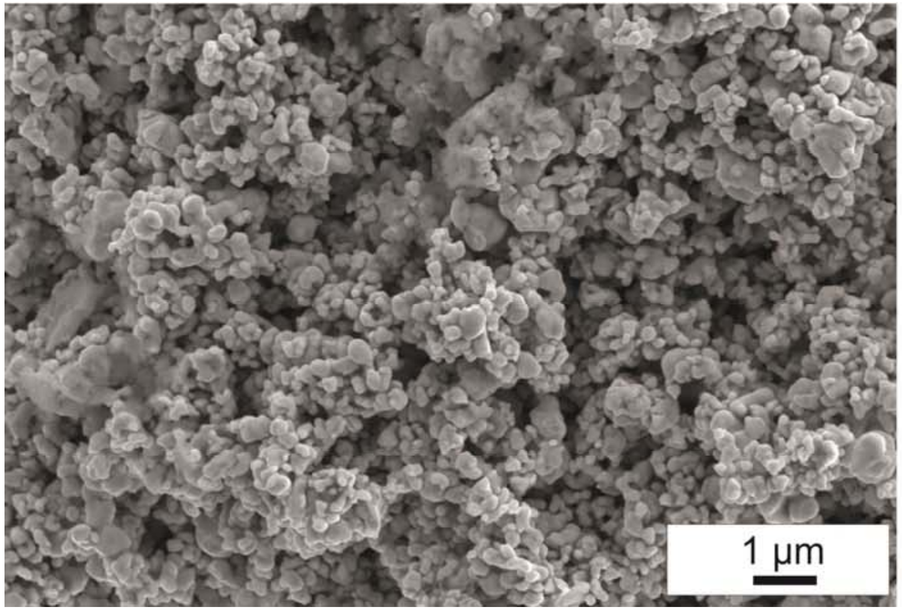
source: http:\\pim-technologies.com



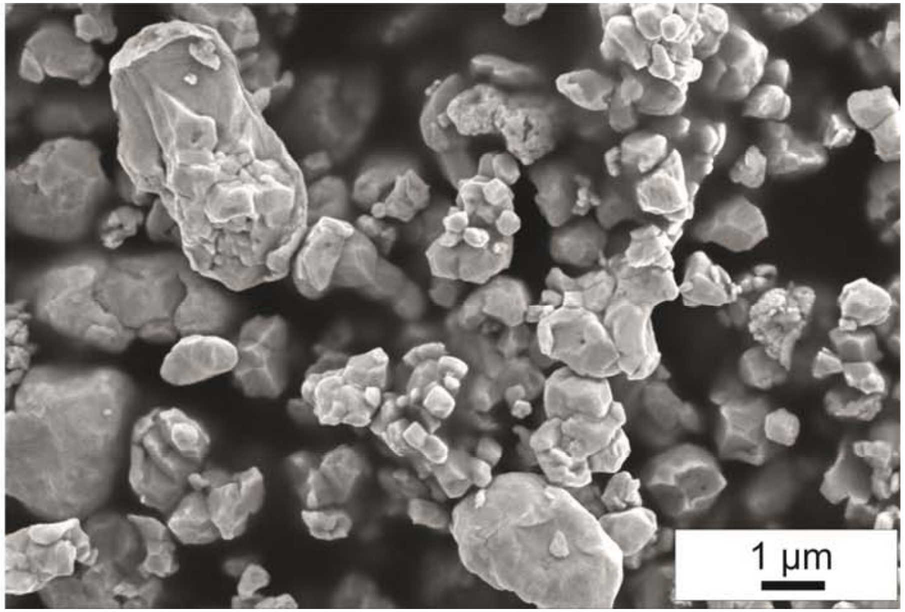
The PIM process for tungsten developed at KIT



The PIM process for tungsten developed at KIT
1. Powder



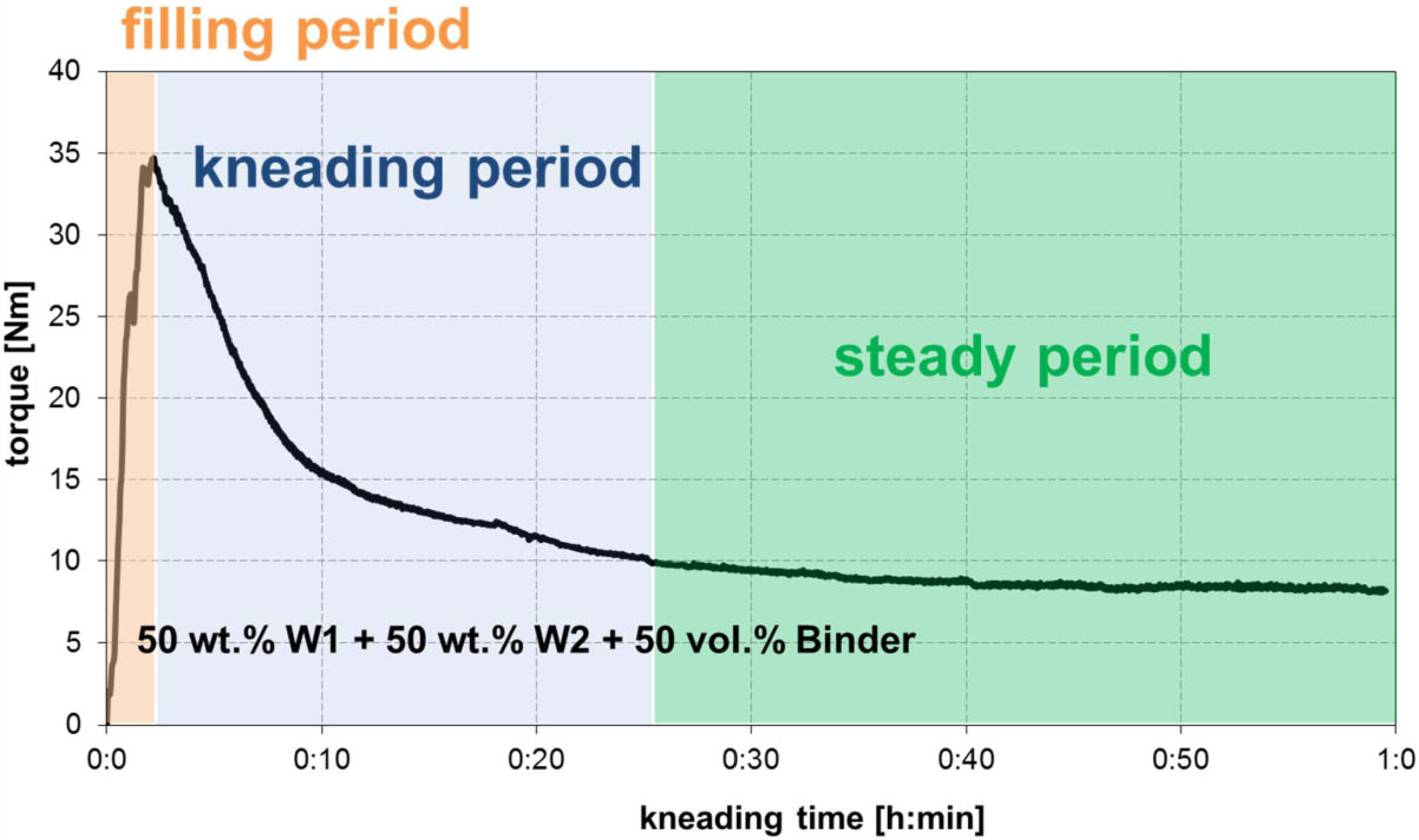
SEM Microstructure tungsten powder W1



SEM Microstructure tungsten powder W2

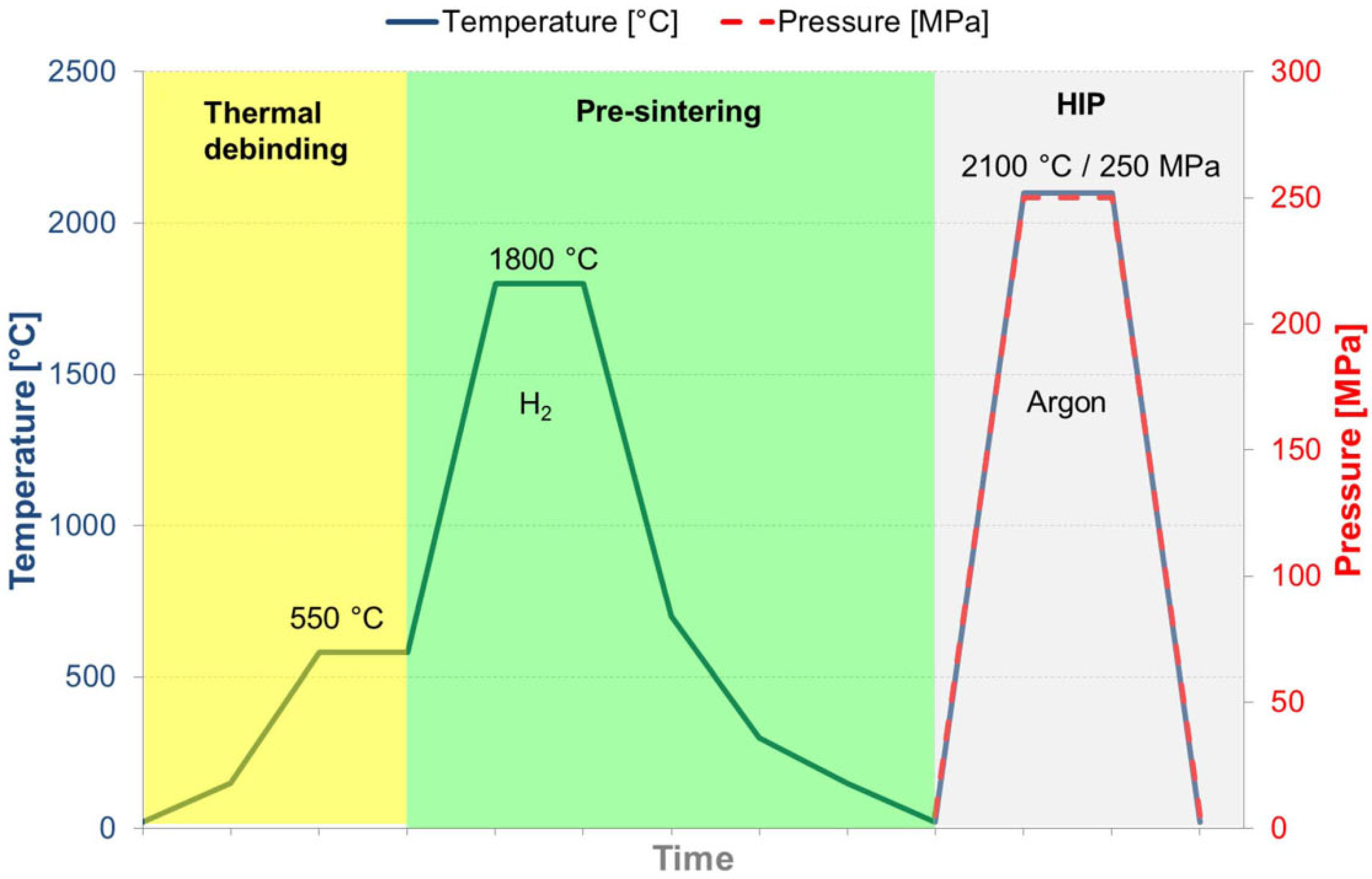
W powder	Particle size [µm FSSS]	D10 [µm]	D50 [µm]	D90 [µm]	BET [m²/g]
W1	0.70	0.14	0.47	1.25	1.27
W2	1.70	0.55	1.80	4.91	0.43

The PIM process for tungsten developed at KIT
2. Feedstock development - kneading



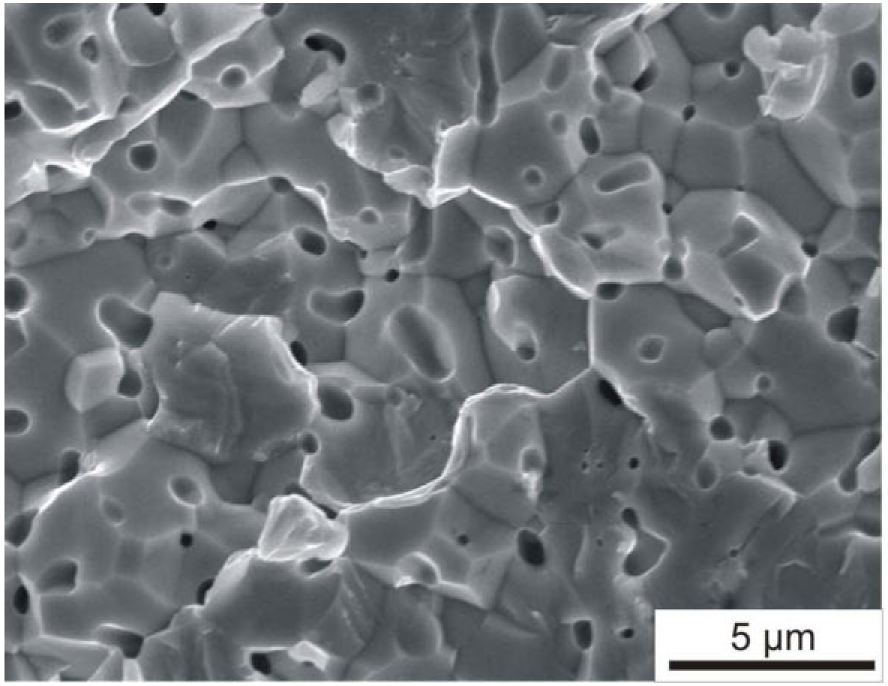
The PIM process for tungsten developed at KIT
3. Injection Molding of green parts

The PIM process for tungsten developed at KIT
4. Heat-treatment process (1)



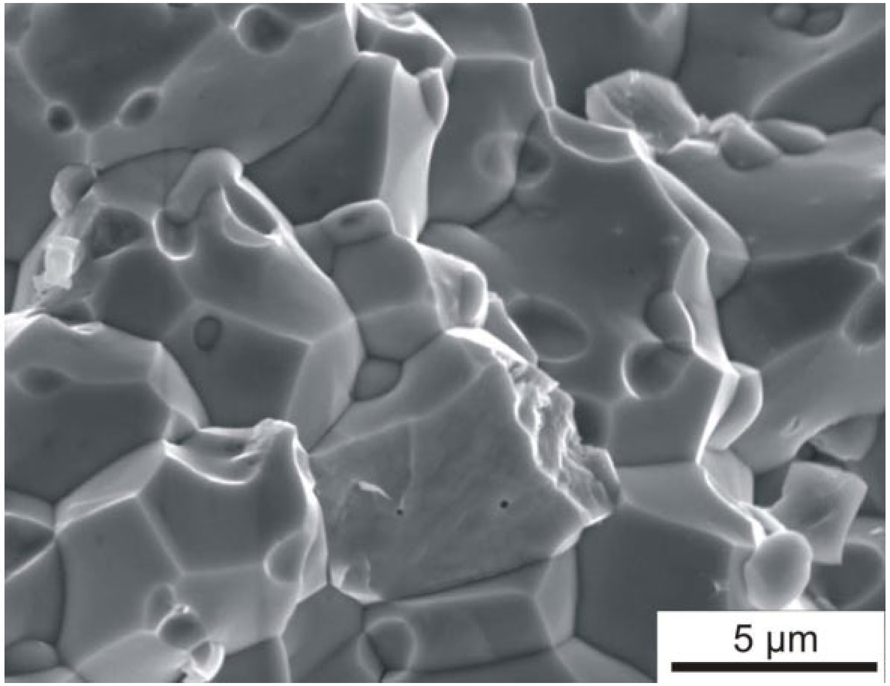
The PIM process for tungsten developed at KIT
4. Heat-treatment process (2)

only pre-sintering | **pre-sintering + HIP**



SEM Microstructure pre-sintering W

Density >95% - closed porosity!!!
Vickers-hardness 420 HV0.1



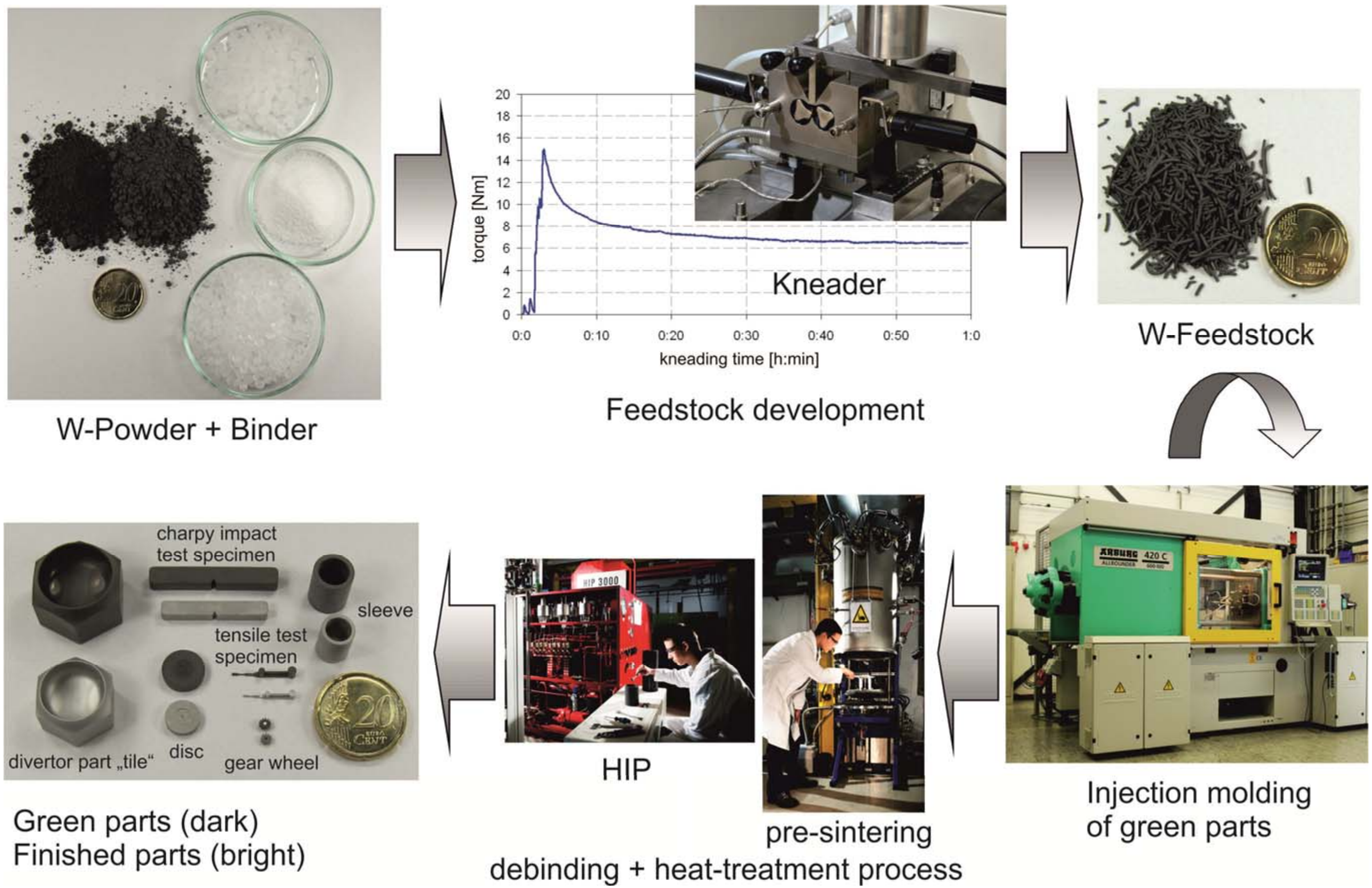
SEM Microstructure pre-sintering +HIP W

Density >98%
Vickers-hardness 457 HV0.1

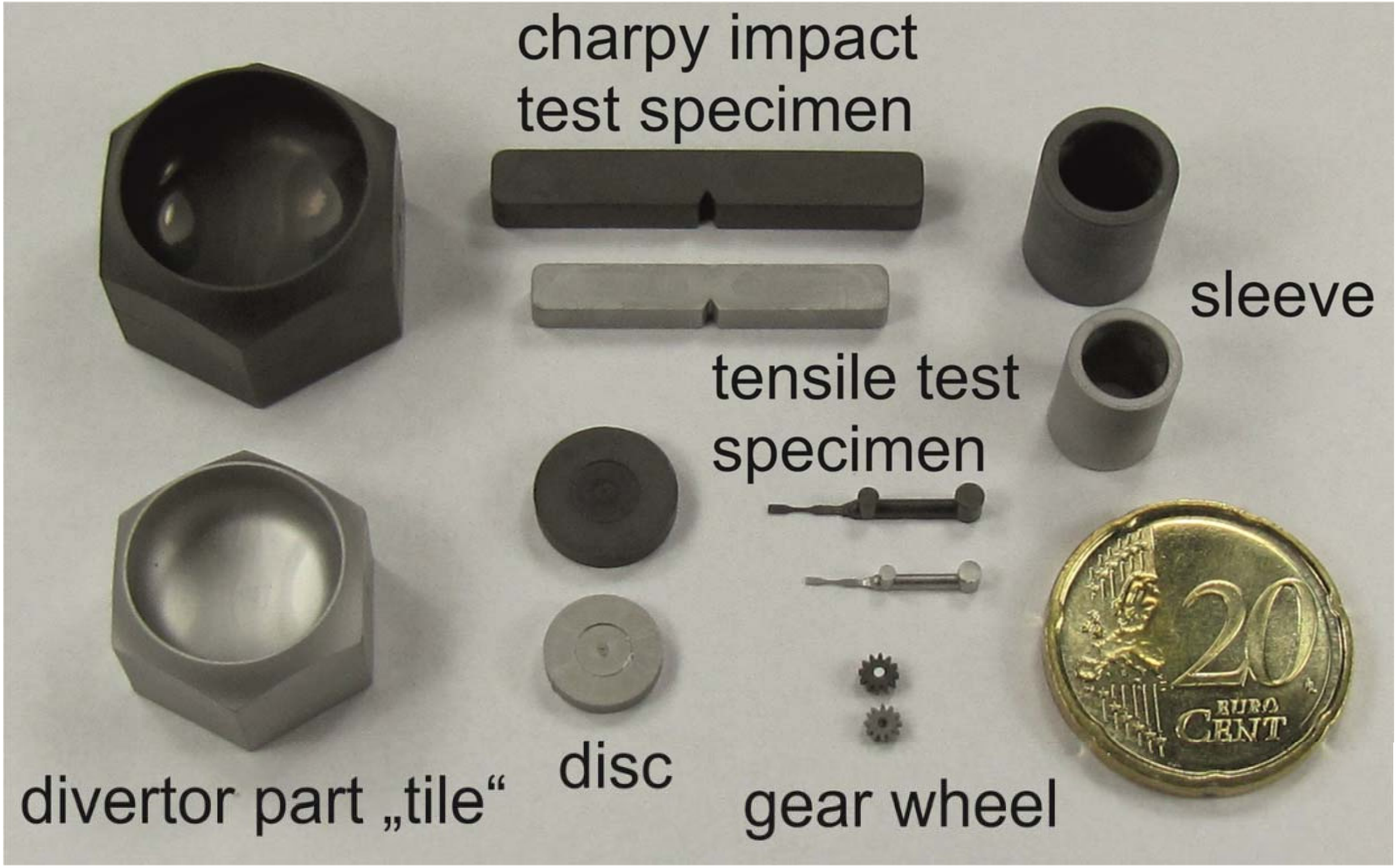
S. Antusch et al., J. Nucl. Mater. 417 (2011) 533-535.

The PIM process for tungsten developed at KIT

Karlsruhe Institute of Technology

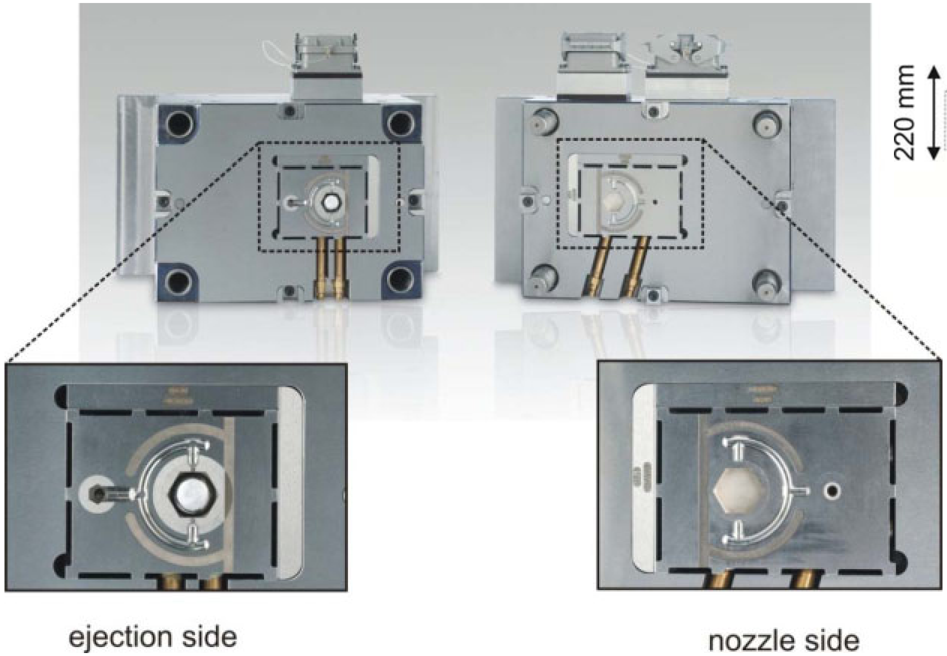


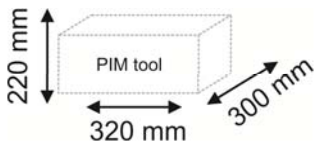
The PIM process for tungsten developed at KIT
5. Tungsten PIM samples

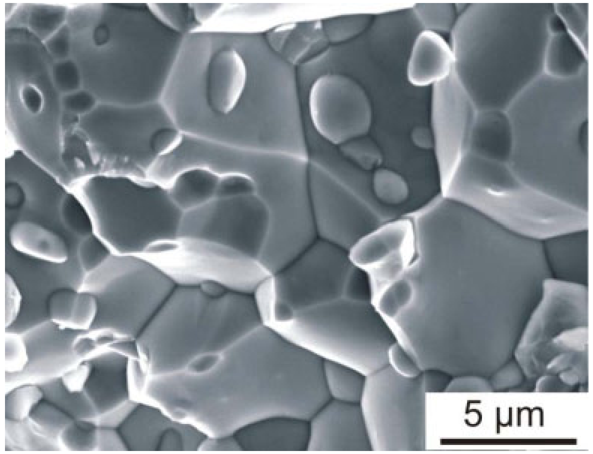


Green parts (dark) and finished parts (bright)

The PIM process for tungsten developed at KIT
5. The divertor W PIM part „tile“



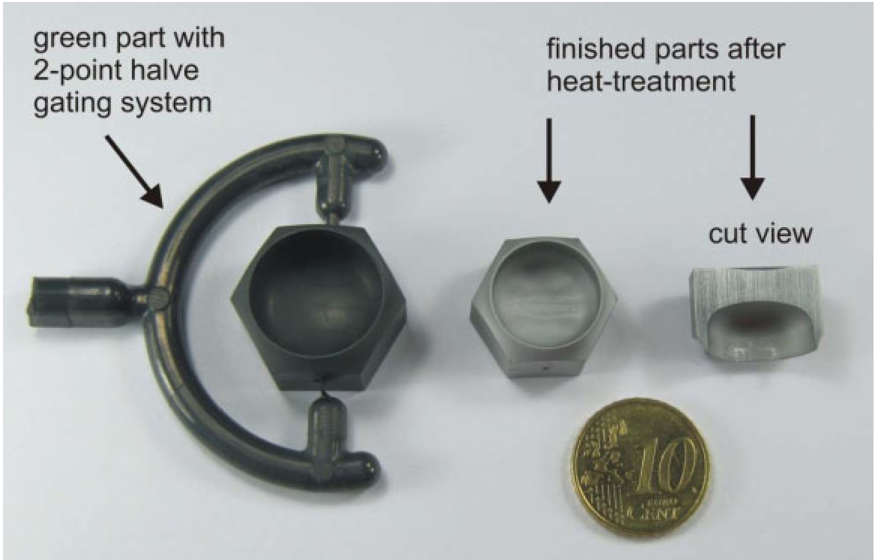




SEM image of the fracture surface: no porosity or cracks

Heat-treatment process:
- pre-sintering (1800 °C, 2 h, H_2) +
- HIP (2100 °C, 3 h, Ar, 250 MPa)

Properties of the finished material:
Vickers-hardness: 457 HV0.1
Density: 98.6 – 99 % TD

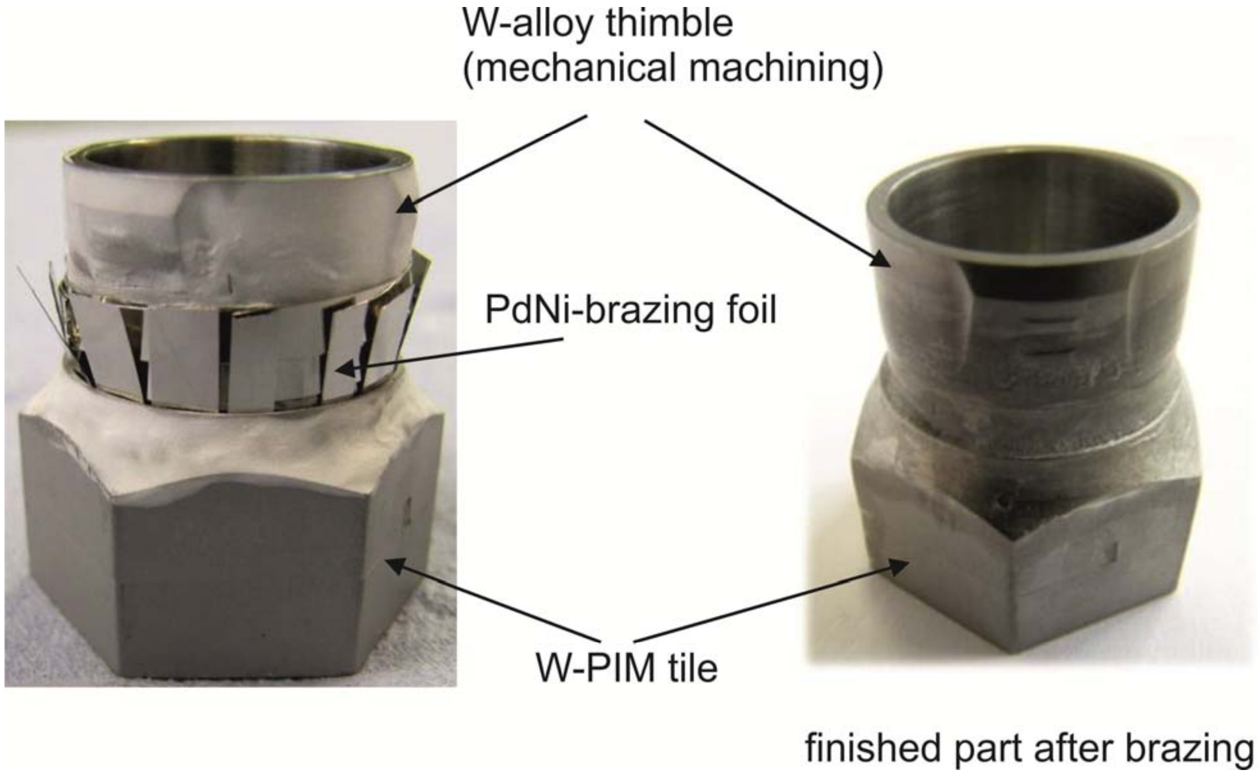


S. Antusch et al., Fusion Engineering and Design, 86 (2011) 1575-1578.

The PIM process for tungsten developed at KIT …joining…

→ Fabrication of the W PIM tile successful

→ Joining via brazing of W PIM tile and W-alloy thimble (produced by mechanical machining)



→ **Mass production process?**

Courtesy of L. Spatafora (Bachelor Thesis 2010)

Material development for PIM

⇒ Material produced by mechanical alloying

(2 h, n-Hexane, ZrO_2 balls + bowl)

⇒ **W-2La_2O_3**

⇒ **W-2Y_2O_3**

PIM parts (small discs) produced

Mill and equipment

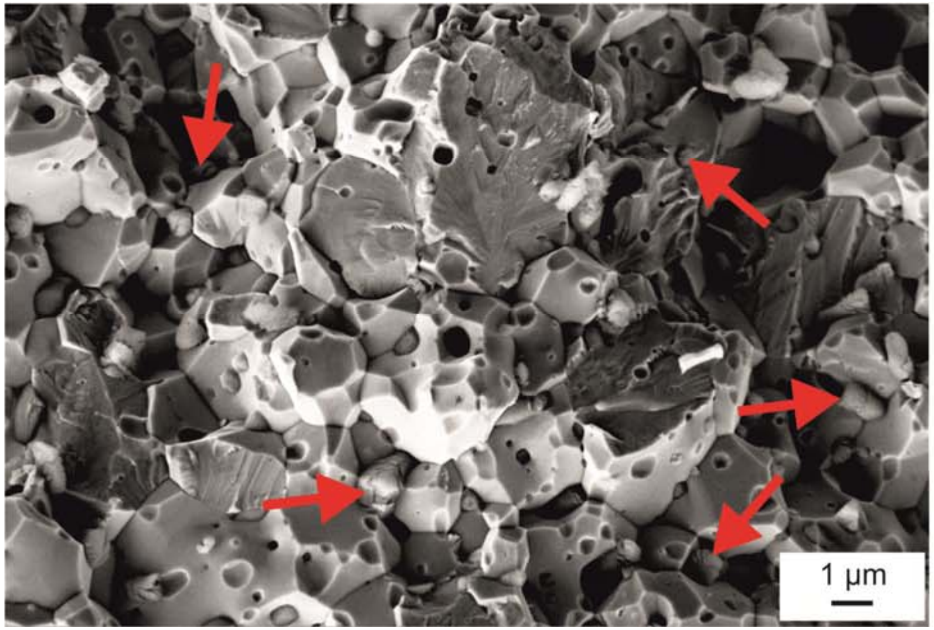
Heat-treatment:

- pre-sintering (1800 °C, 2 h, H_2) +
- HIP (2100 °C, 3 h, Ar, 250 MPa)

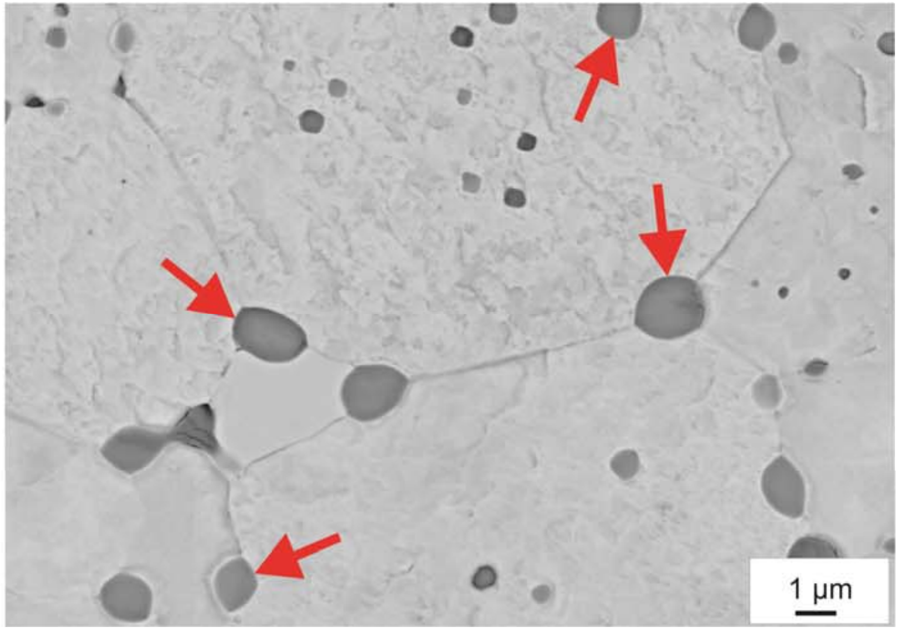
Material	Theoretical density (% TD)	Vickers-hardness (HV0.1)
W	98.6 – 99.0	457
W-2La_2O_3	96.5 – 97.2	586
W-2Y_2O_3	96.3 – 97.1	617

Material development for PIM

$\Rightarrow$ **W-2La$_2$O$_3$**



SEM Microstructure (fracture surface)

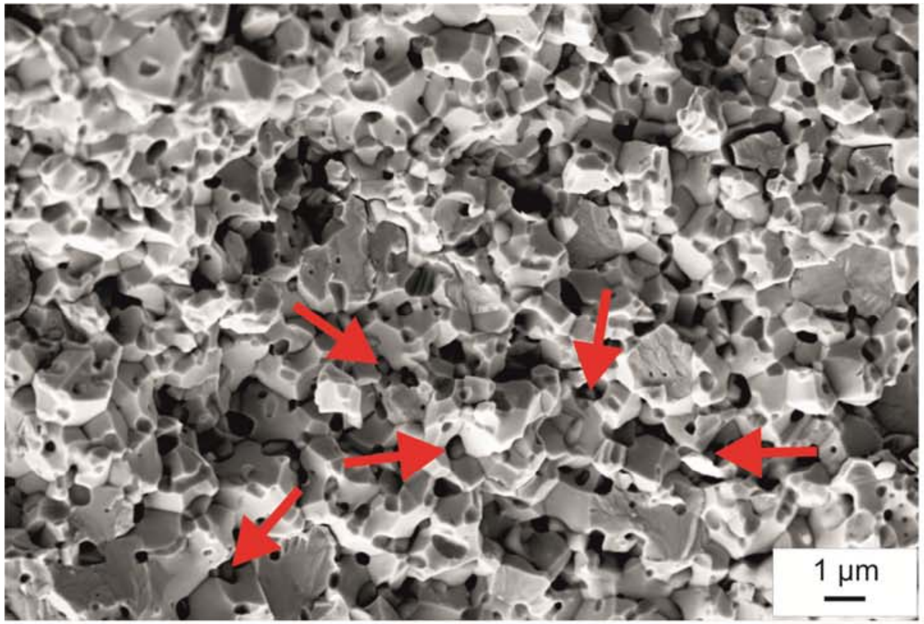


SEM Microstructure (metallographic section)

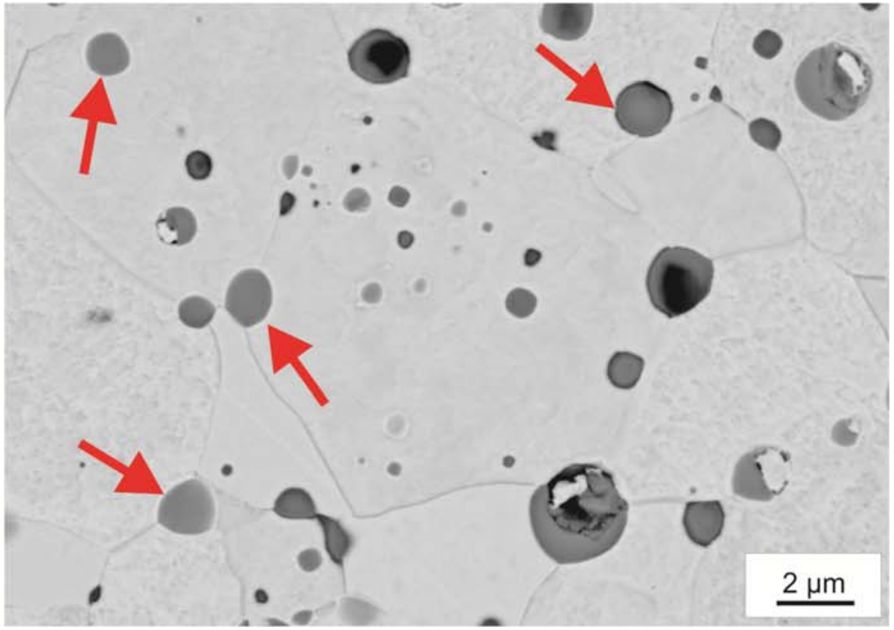
A selection of La_2O_3-particles is marked by arrows...

Material development for PIM

$\Rightarrow$ **W-2Y_2O_3**



SEM Microstructure (fracture surface)



SEM Microstructure (metallographic section)

A selection of Y_2O_3-particles is marked by arrows...

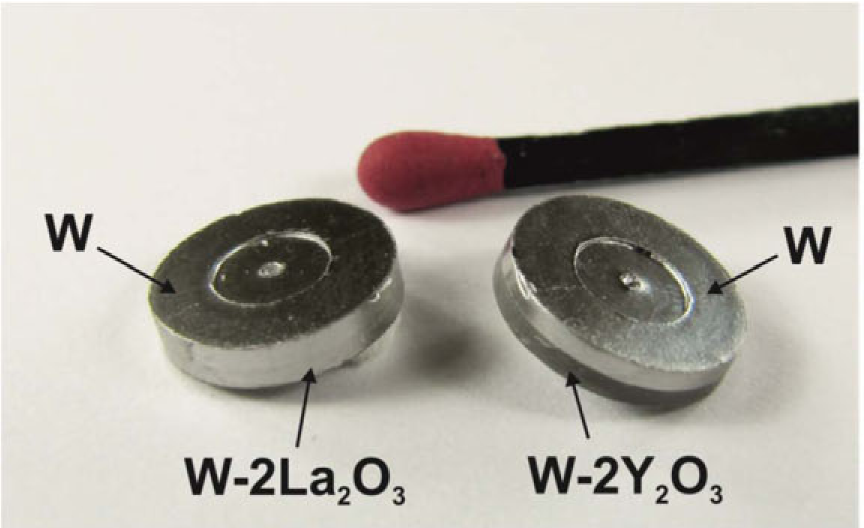
2-Component tungsten PIM

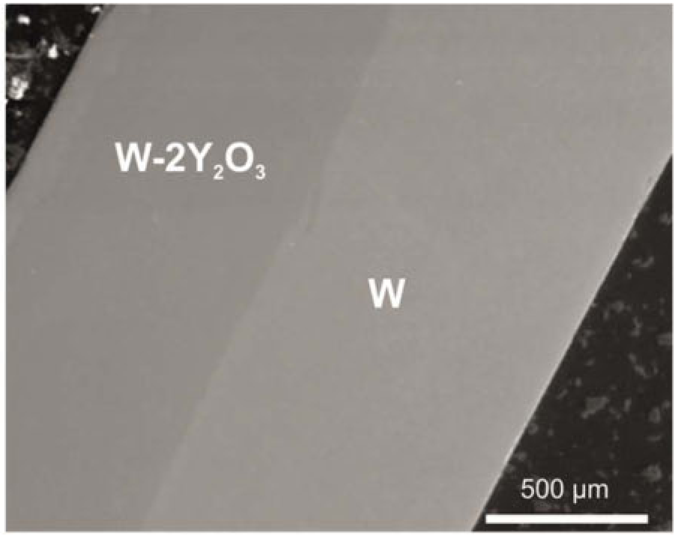
Pretests via insert 2-Component PIM:

Material produced by mechanical alloying

Heat-treatment:
- pre-sintering (1800 °C, 2 h, H_2) +
- HIP (2100 °C, 3 h, Ar, 250 MPa)

⇒ **W + W-2La_2O_3 / W + W-2Y_2O_3** PIM samples produced + characterized





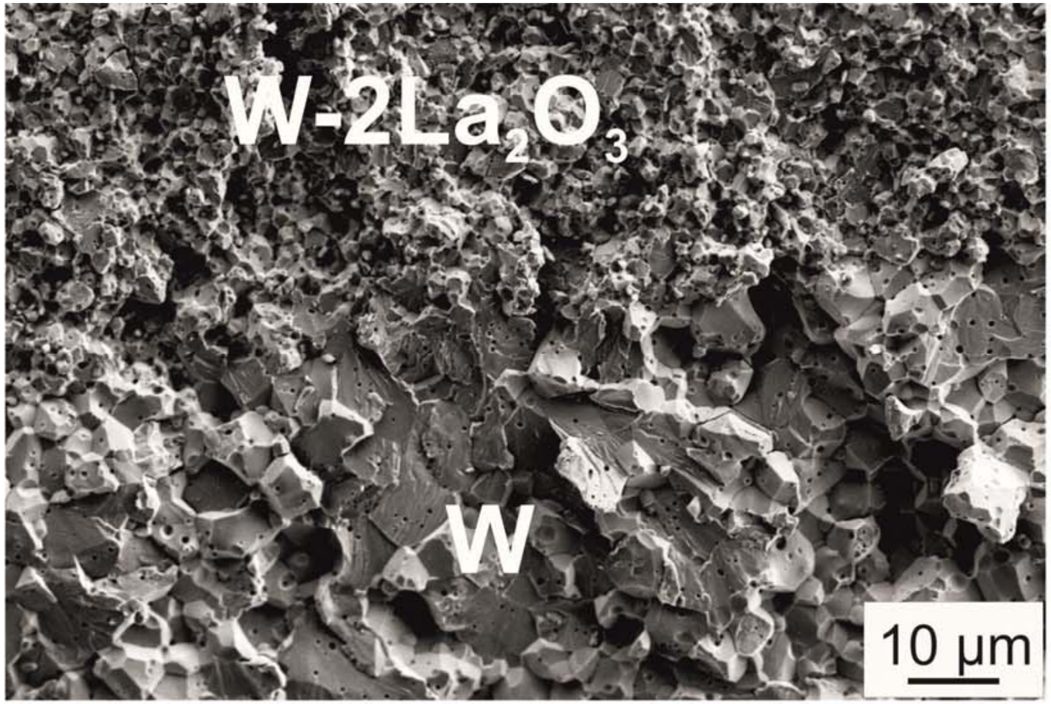
S. Antusch et al., Fusion Science and Technology (2012) submitted.

2-Component tungsten PIM

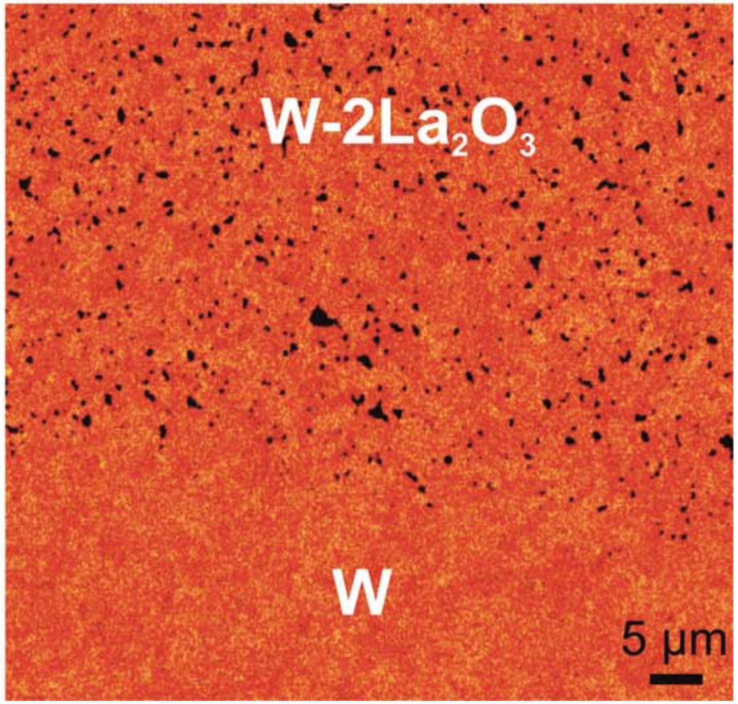
Pretests via insert 2-Component PIM:

⇒ **W + W-2La_2O_3**

⇒ Joining seam: without cracks or gaps
⇒ Material connecting successful



SEM Microstructure (fracture surface)



AES Map (metallographic section)

black: La_2O_3
red: W

2-Component tungsten PIM

Pretests via insert 2-Component PIM:

⇒ **W + W-2Y_2O_3**

⇒ Joining seam: without cracks or gaps
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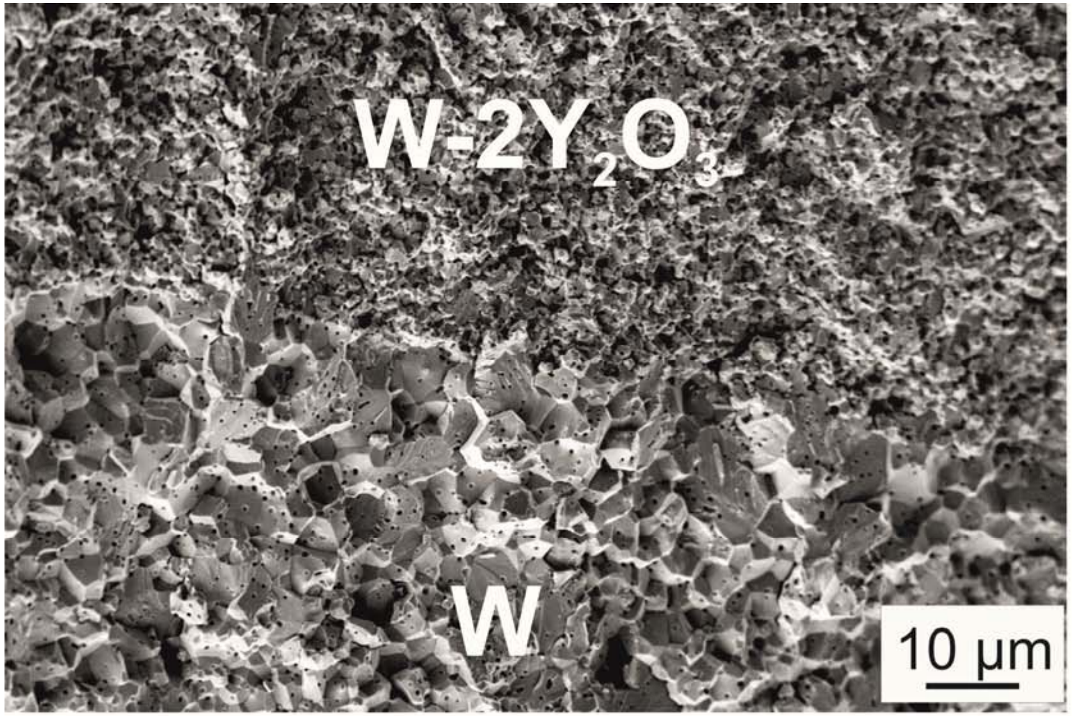
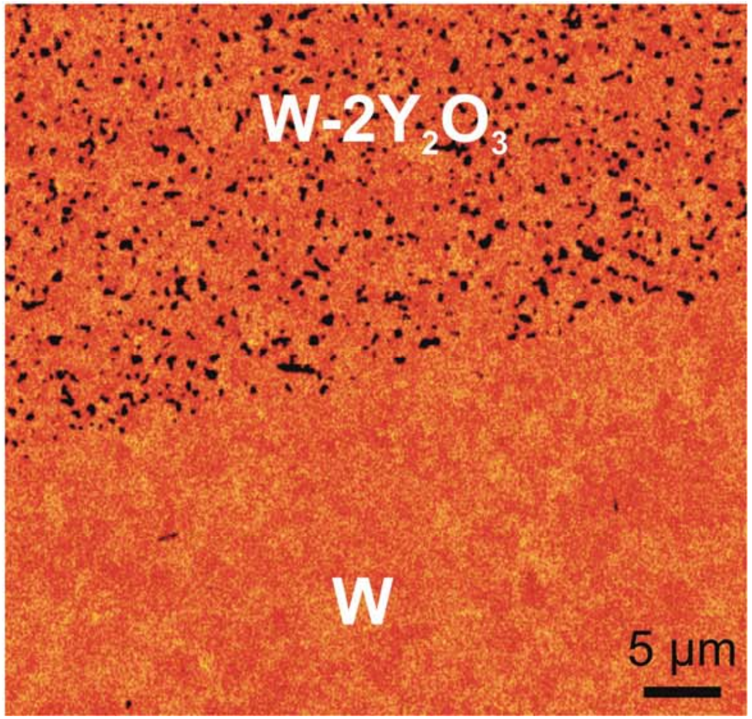


SEM Microstructure (fracture surface)



AES Map (metallographic section)

black: Y_2O_3
red: W

2-Component tungsten PIM

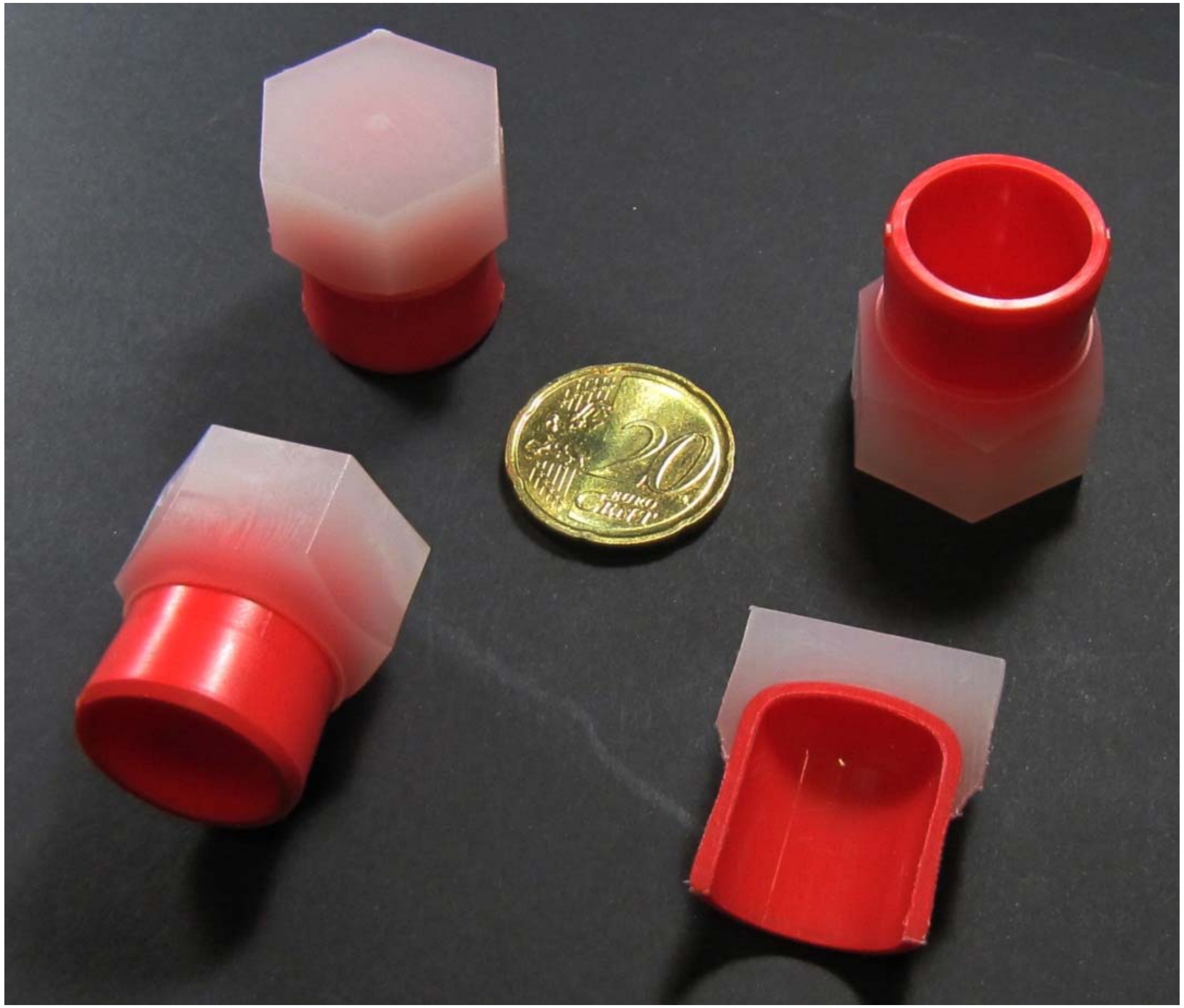
Knowledge transfer - from pretests to real 2-Component Powder Injection Molding process: material combination, heat-treatment process, shrinkage…

⇒ **Design and Engineering of a fully automatic 2-Component PIM tool**

⇒ Tile and thimble in one unit with / without joining layer

⇒ Joining of 2 different materials without brazing in 1 process step

2-Component tungsten PIM
…first samples…



Bicolor plastic test samples to demonstrate the functionality of the new tool

2-Component tungsten PIM
…next steps….

⇒ Implementing of the new 2-Component PIM tool

⇒ Producing of 2-Component PIM parts:

- ⇒ **W tile + W-2La_2O_3 timble**

- ⇒ **W tile + W-2Y_2O_3 thimble**

⇒ Adaption of the Heat-treatment process

⇒ Characterization (density, hardness, quality of the joining zone…)

Goals for 2012

⇒ 1-finger mockup produced via 2-Component W PIM

⇒ feasibility study / demonstration of joining via 2-Component W PIM

Summary

- **Material & process development for W PIM at KIT**
  - Development of a suitable W feedstock: W1 + W2 (50:50) 50 vol.%
  - Optimization of the heat-treatment process: pre-sintering + HIP
  - Producing of W PIM parts
    → Properties of the finished divertor part W tile:
    → Density: 98.6 – 99 % T.D.
    → Vickers-hardness: 457 HV0.1
    → Microstructure without porosity or cracks
  - Development of new W PIM materials:
    → W-2La_2O_3
    → W-2Y_2O_3
  - Pretests via insert 2-Component W PIM
    → Investigation of the joining zone quality:
    → Joining seam: without cracks or gaps
    → Material connecting successful
  - Design & Engineering of a new fully automatic 2-Component W PIM tool

Outlook

- Establish 2-Component tungsten Powder Injection Molding at KIT
- Development of new materials for multicomponent W PIM
- Material characterization:
  → Charpy and tensile tests
  → High Heat Flux Tests (IPP Garching / FZ Jülich

Powder Injection Molding:

→ Mass production & joining process

→ Time & cost effective near-net-shape forming process

→ Shape complexity and high final density

Thank you very much!

PL FUSION

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