Karlsruhe Institute of Technology

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MULTICOMPONENT POWDER INJECTION MOLDING AS METHOD FOR MASS PRODUCTION, JOINING, AND MATERIAL DEVELOPMENT FOR TUNGSTEN ARMOUR MATERIALS

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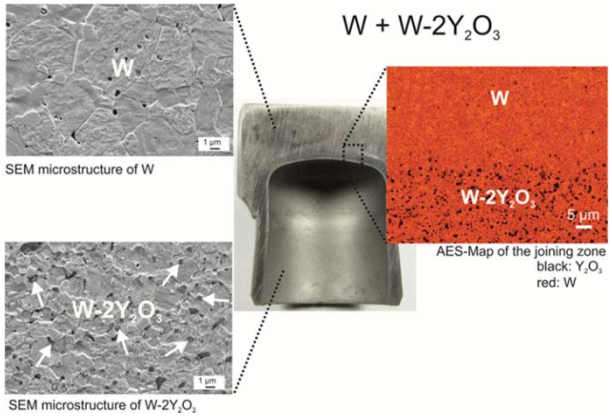
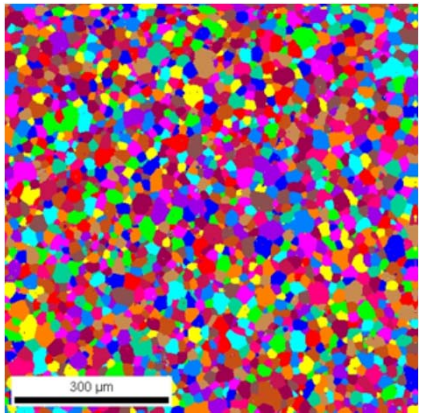
INSTITUTE FOR APPLIED MATERIALS





Outline

- Powder Injection Molding @ KIT
- Mass production of tungsten parts
- Powder Injection Molding as joining process
- Development of new materials

Summary

Outline

- **Powder Injection Molding @ KIT**
- Mass production of tungsten parts
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Summary

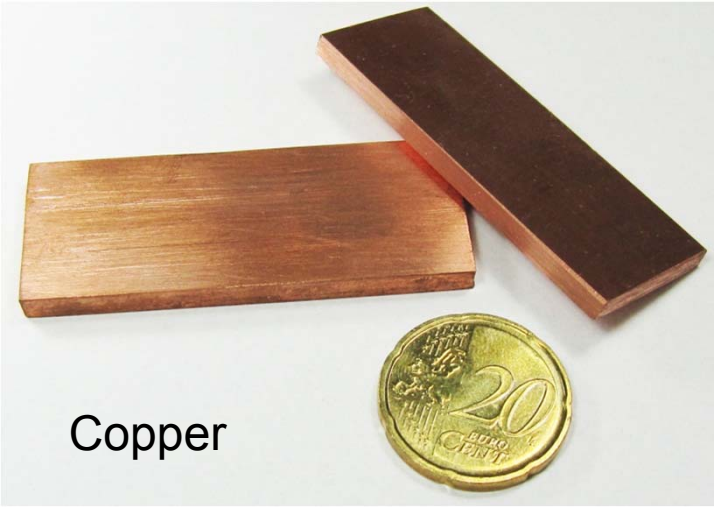
Powder Injection Molding @

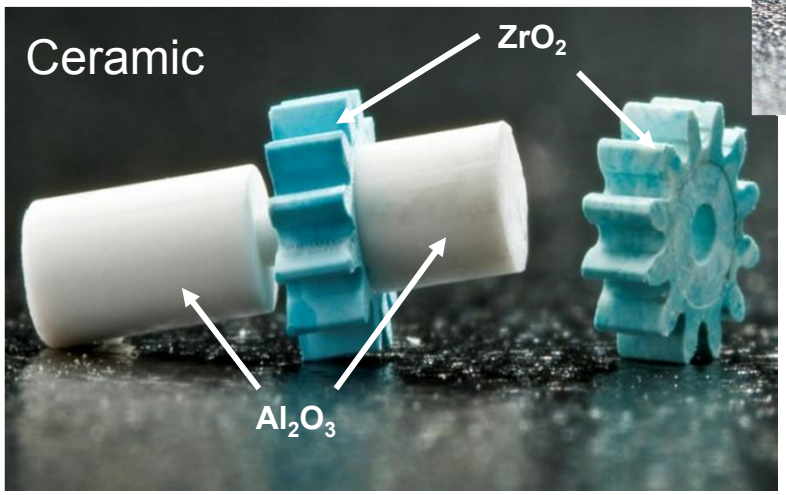
MANUFACTURING TECHNOLOGY

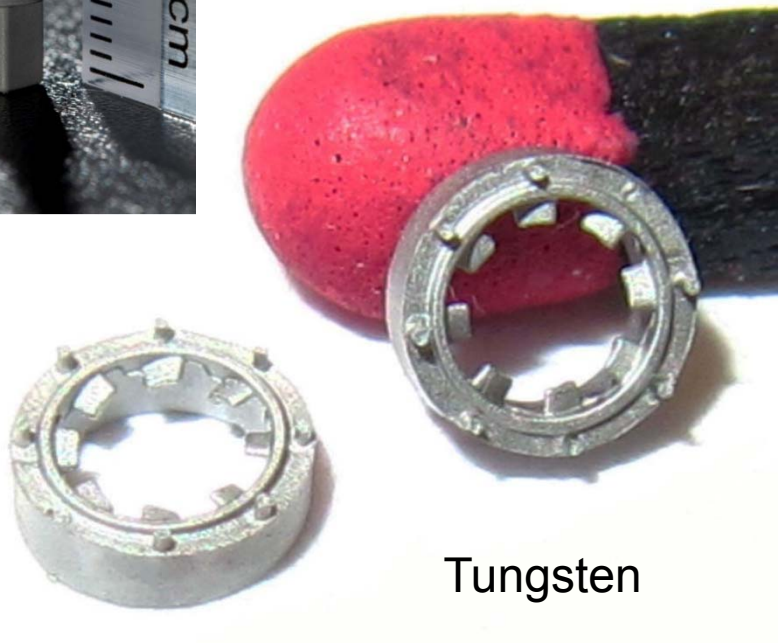
Metal Injection Molding (MIM)

Ceramic Injection Molding (CIM)

Powder Injection Molding @







Smallest ZrO_2 gear wheel of the world:
outer-∅ 275 µm

Outline

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Summary

Mass production of tungsten parts

…The PIM process for tungsten developed @

Karlsruhe Institute of Technology

Material development

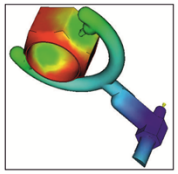
Powder

Binder

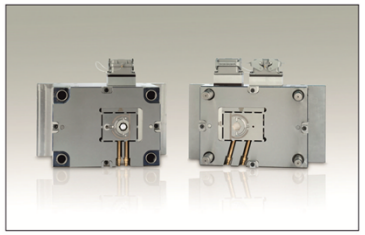
Mixing / Kneading / Extrusion

Feedstock

Design + engineering of a tool



Filling simulation



PIM-tool

Injection molding of green parts

Debinding / Heat-treatment

Green parts (dark), **finished parts** (brigth)

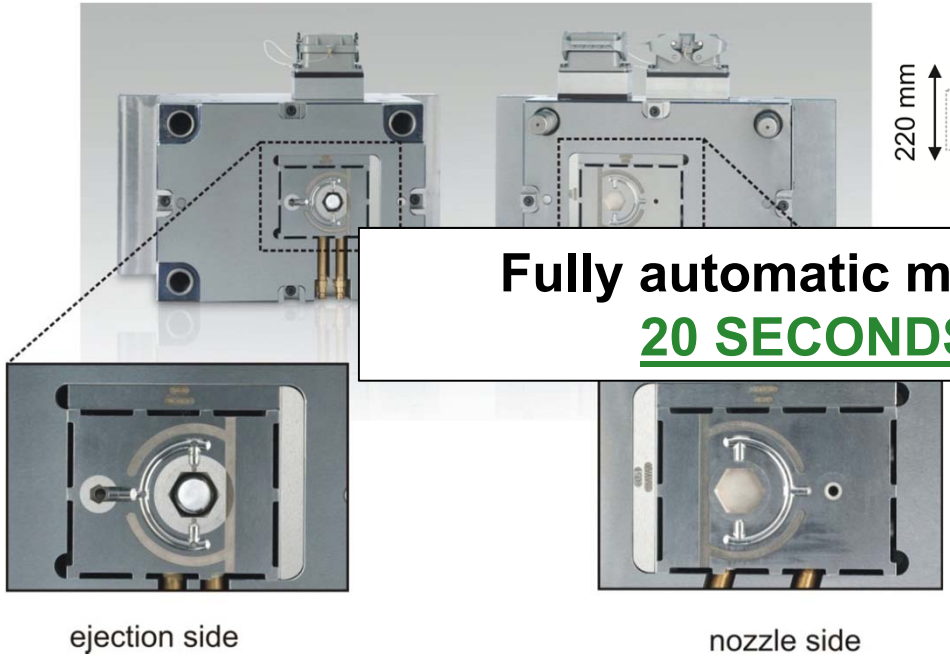
IAM Institute for Applied Materials

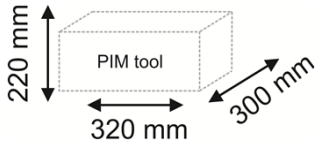
Mass production of tungsten parts

…Production of green parts…

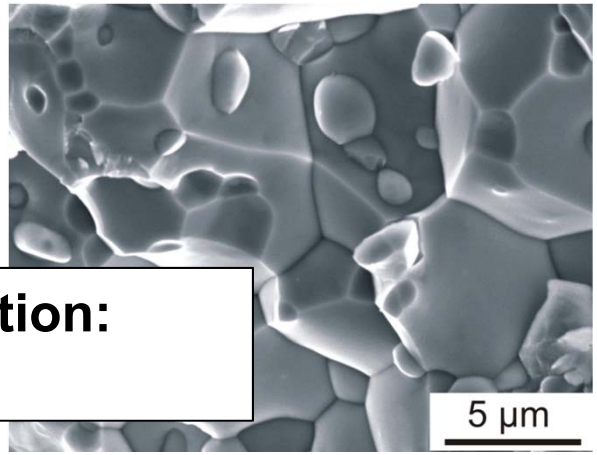
Mass production of tungsten parts

…The divertor W PIM part „tile“…





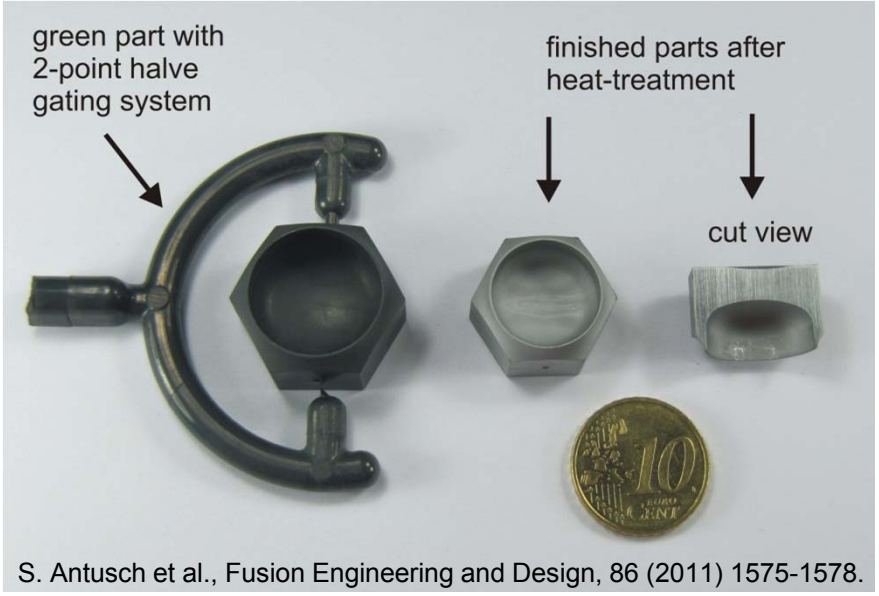
Fully automatic mass production:
20 SECONDS for 1 Part



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.

Outline

- Powder Injection Molding @ KIT
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- **Powder Injection Molding as joining process**
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Summary

Powder Injection Molding as joining process

…Used powders…

Powder particle size (as-delivered):

- W 2 - 4 µm
- La_2O_3 1 - 2 µm
- Y_2O_3 2 - 3 µm

powder mixing

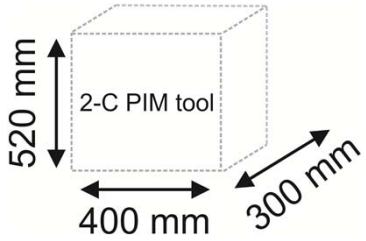
Material development:

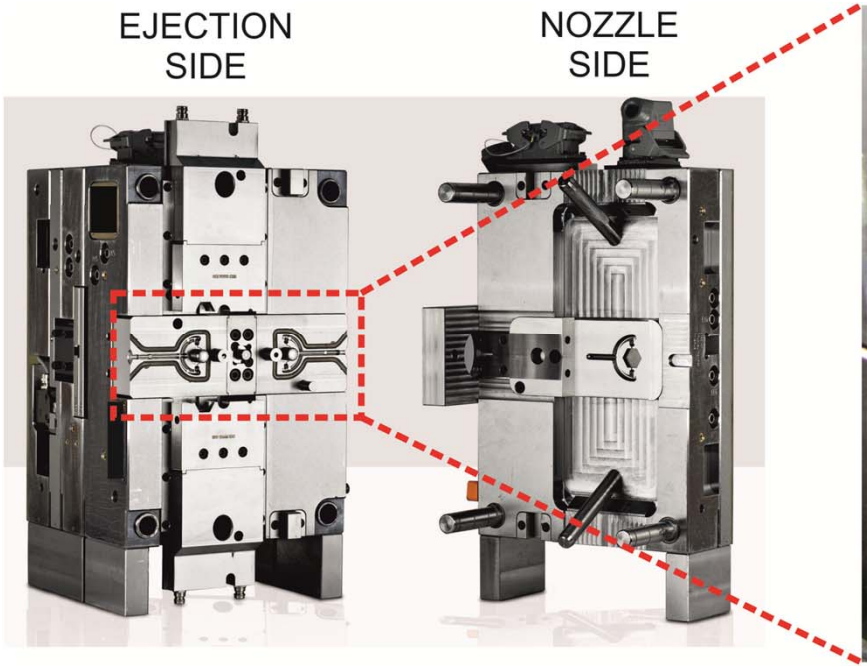
- W (pure)
- W-2La_2O_3 (5.7 vol.-% La_2O_3)
- W-2Y_2O_3 (8.1 vol.-% Y_2O_3)

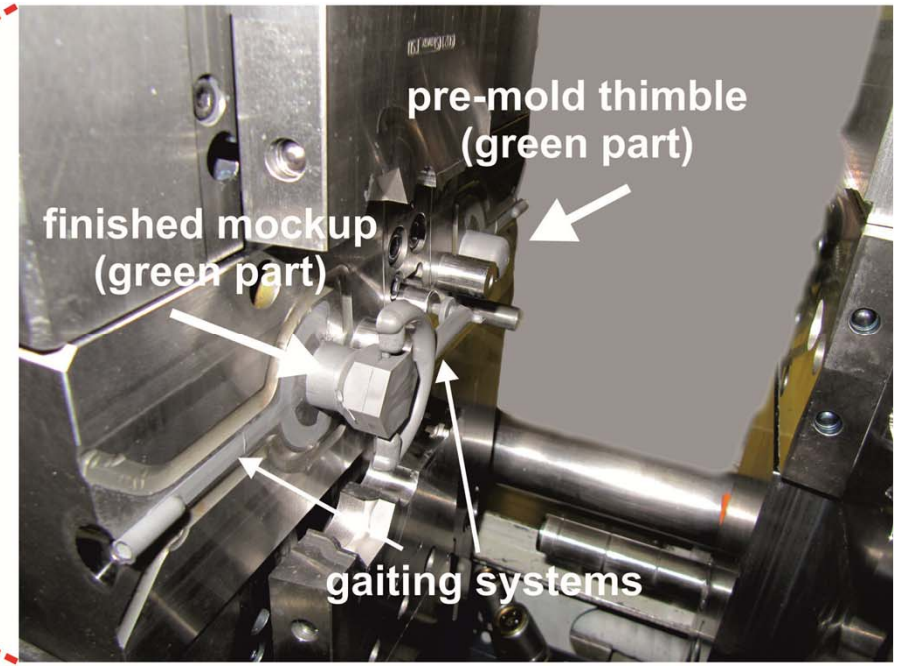
Powder Injection Molding as joining process

…Production of multicomponent W PIM divertor parts…

Fully automatic mass production:
50 SECONDS for 1 Part







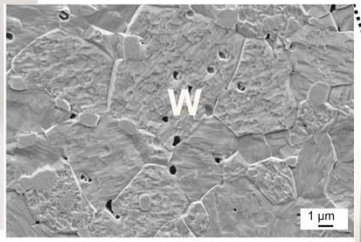
Powder Injection Molding as joining process

…Green parts vs. Finished parts…

Powder Injection Molding as joining process

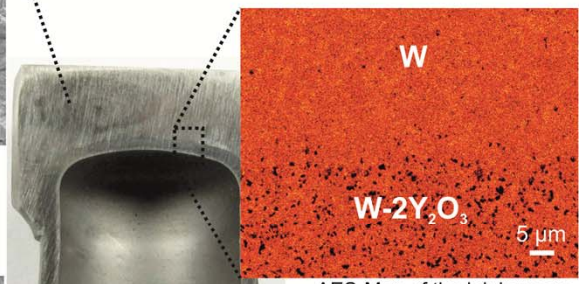
…Characterization of the joining zone quality…

Joining without brazing

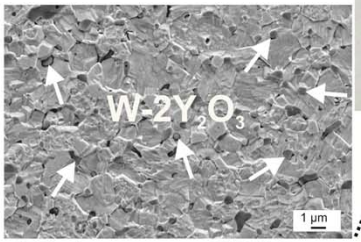


SEM microstructure of W

W + W-2Y_2O_3



AES-Map of the joining zone
black: Y_2O_3
red: W



SEM microstructure of W-2Y_2O_3

→ High quality of the joint

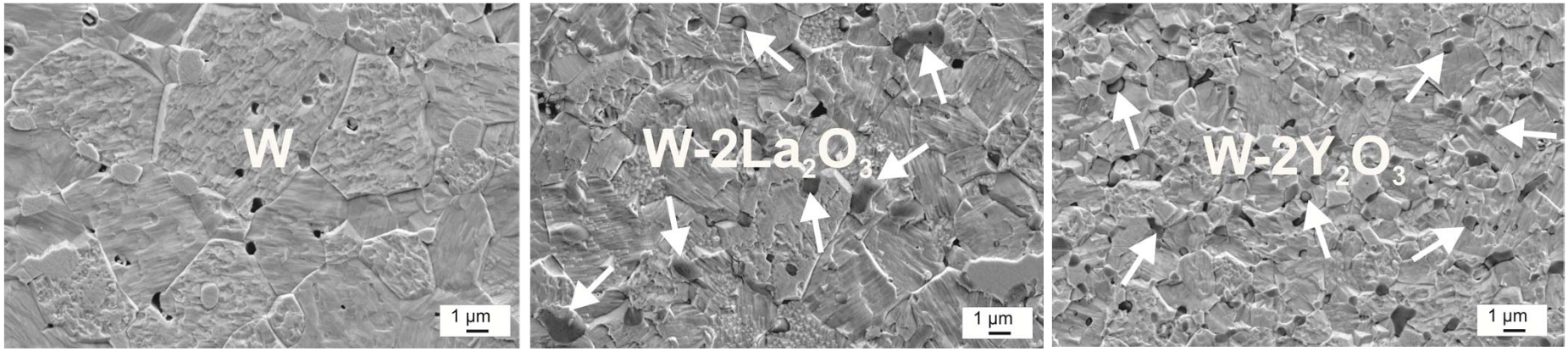
→ Material joining successful

→ No gaps or cracks in the seam of the joining zone

S. Antusch et al., J. of Fusion Engineering and Design (2013).

Powder Injection Molding as joining process

…Material properties…



SEM Microstructure

Material	Theoretical density (% TD)	Vickers-hardness (HV0.1)	Grain size (µm)
W	98.6 - 99.0	457	5 - 7
$W\text{-}2La_2O_3$	98.5 - 98.9	588	>3
$W\text{-}2Y_2O_3$	98.3 - 98.7	619	<3

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Development of new materials

…Used powders…

Powder particle size (as-delivered):

- W 2 - 4 µm
- La_2O_3 1 - 2 µm
- Y_2O_3 2 - 3 µm
- TiC 50 – 80 nm
- TaC 1 – 2 µm

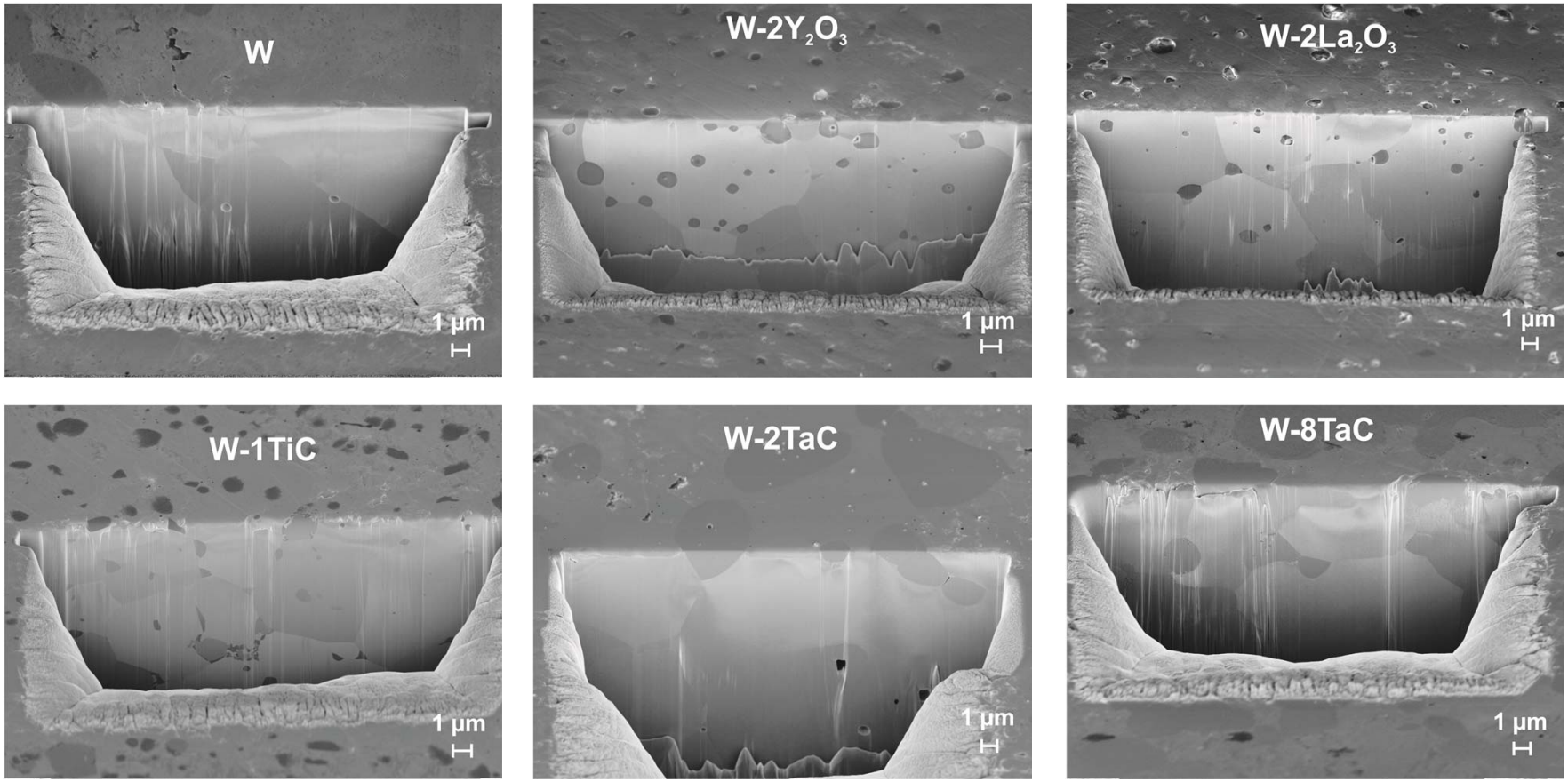
powder mixing

Material development:

- W (pure)
- W-2La_2O_3 (5.7 vol.-% La_2O_3)
- W-2Y_2O_3 (8.1 vol.-% Y_2O_3)
- W-1TiC (3.8 vol.-% TiC)
- W-2TaC (2.7 vol.-% TaC)
- W-8TaC (10.7 vol.-% TaC)

Development of new materials

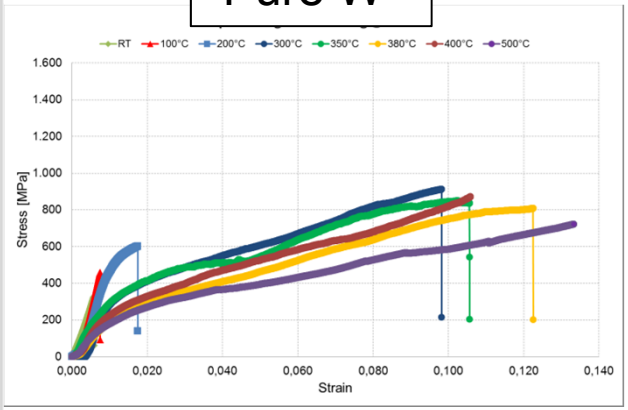
…Microstructure…



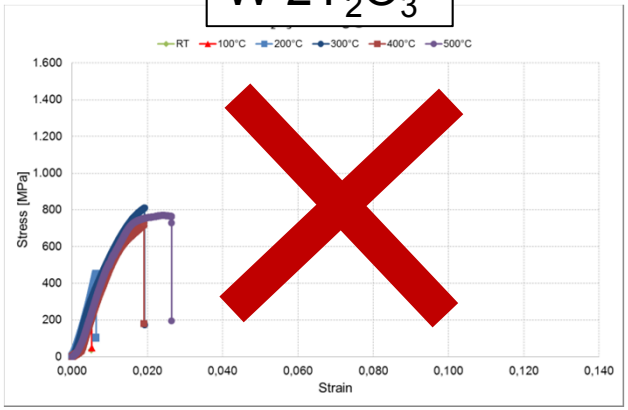
Development of new materials

…4-Point bending tests 20° C to 500 °C…

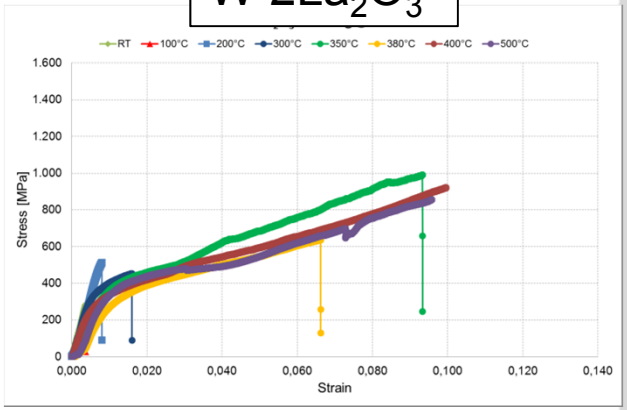
Pure W



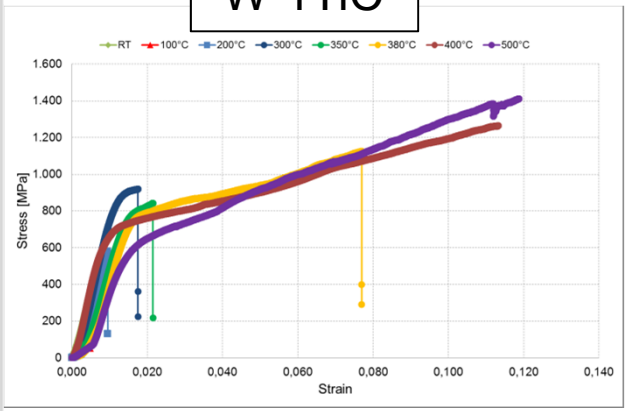
$W\text{-}2Y_2O_3$



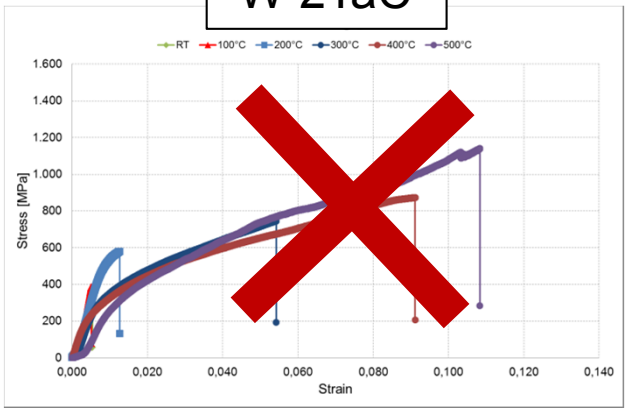
$W\text{-}2La_2O_3$



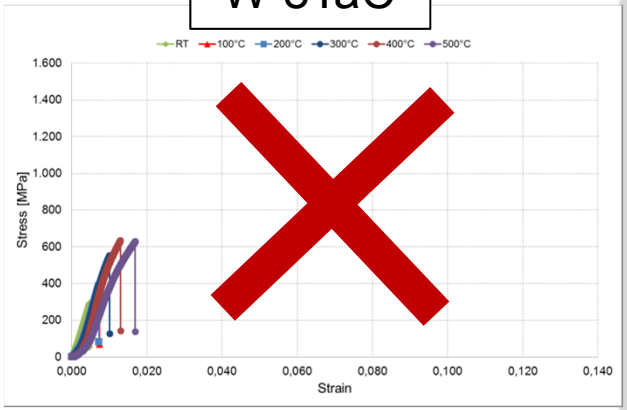
W-1TiC



W-2TaC



W-8TaC



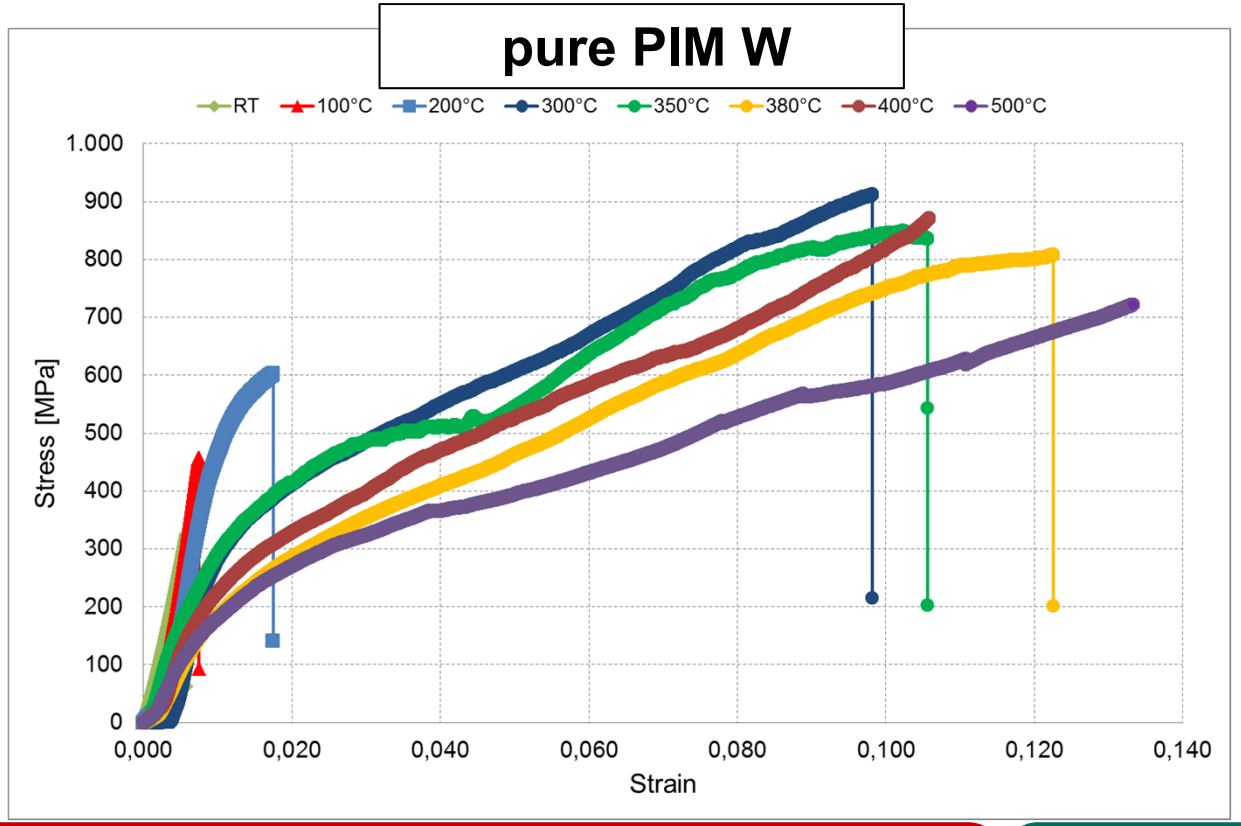
Sample geometry: (12 x 1 x 1) mm

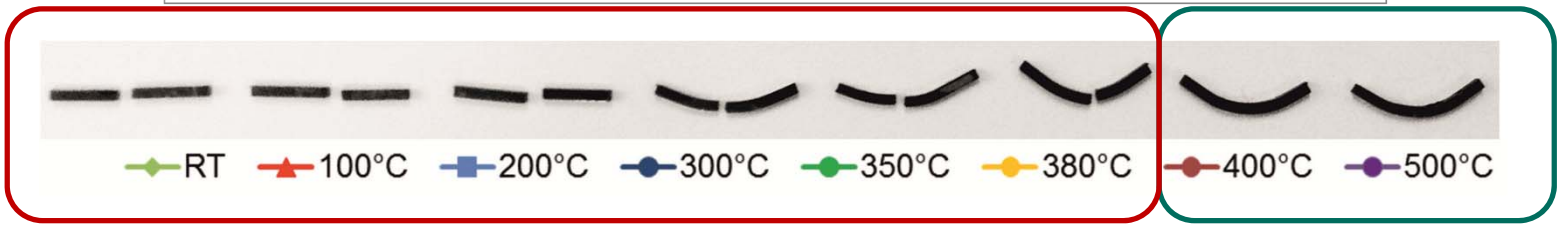
Constant strain rate: 0.0330 mm/min

Notched samples

Development of new materials

…4-Point bending tests 20° C to 500 °C…





Brittle

Ductile

Development of new materials

…Thermal shock testing with e-beam in JUDITH-1…

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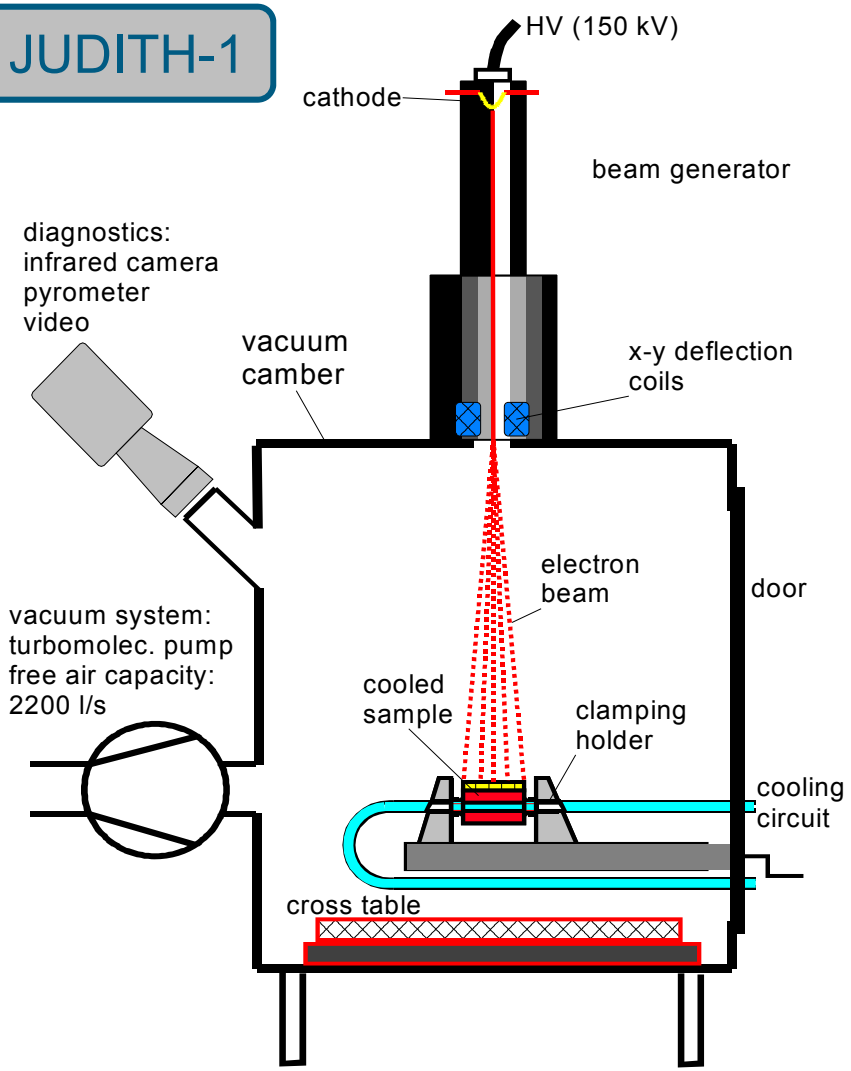
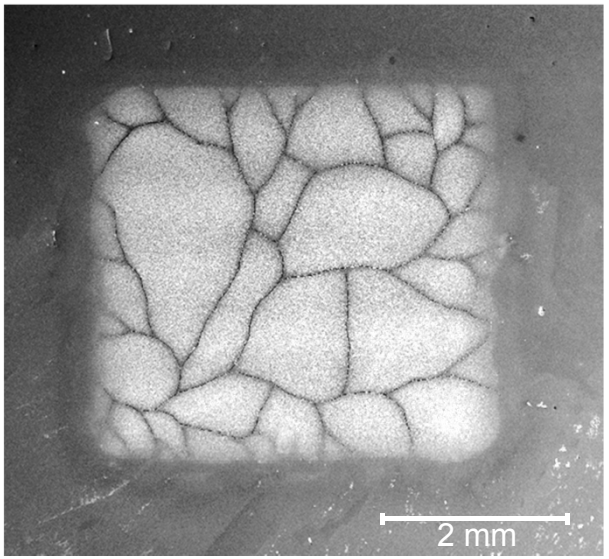
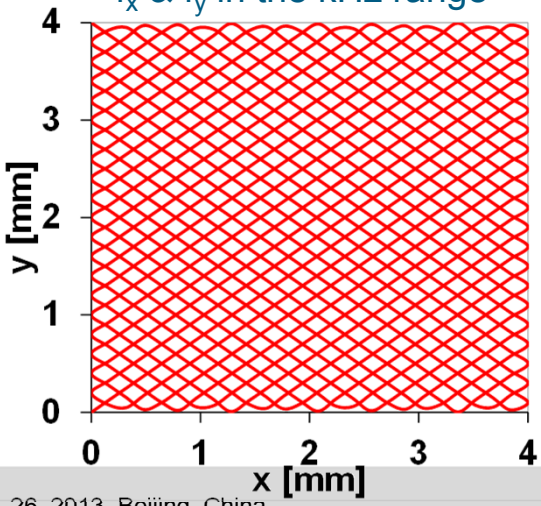
JUDITH-1

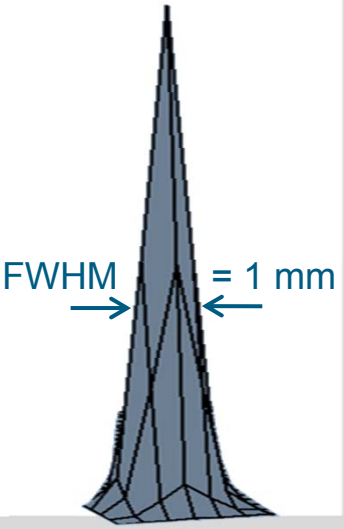


Courtesy of G. Pintsuk (FZJ)



f_x & f_y in the kHz range





Total power: 60 kW

Acceleration voltage: 120 kV

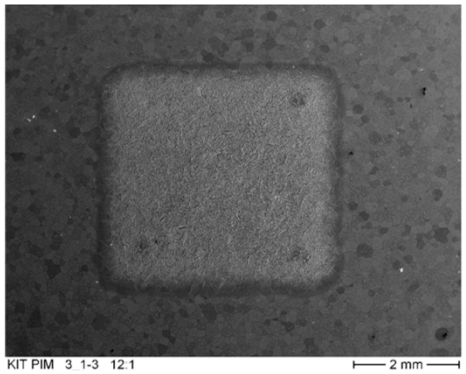
Development of new materials

…Thermal shock testing with e-beam in JUDITH-1…

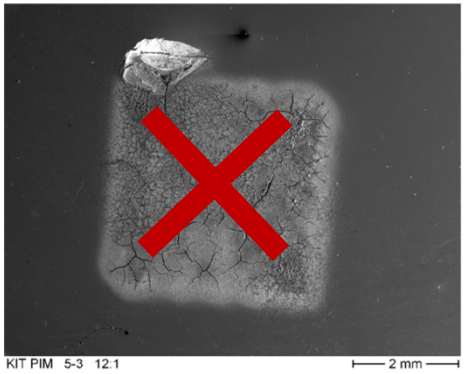
Courtesy of G. Pintsuk (FZJ)

#	T [°C]	P_{abs} [GW/m²]	Δt [ms]	E_{abs} [MJ/m²]	FHF [MW/m²*s$^{1/2}$]	# shots
C	1000	0.38	1	0.38	12	1000

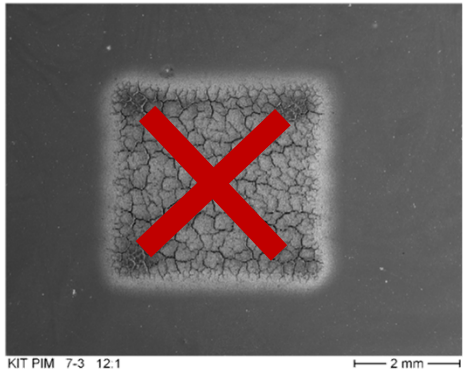
pure W



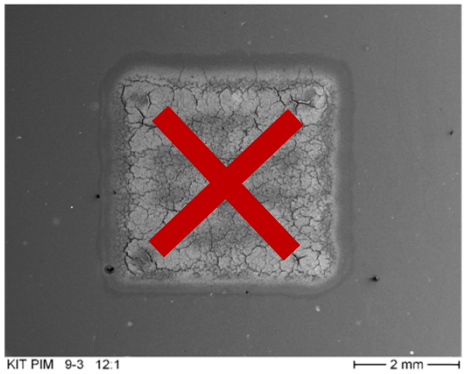
$W\text{-}2Y_2O_3$



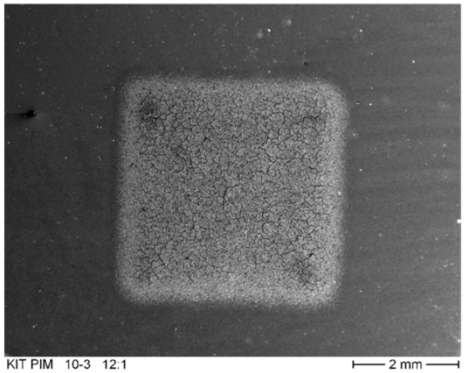
$W\text{-}2La_2O_3$



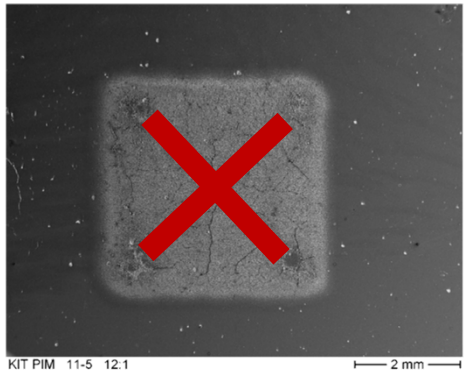
W-1TiC



W-2TaC



W-8TaC



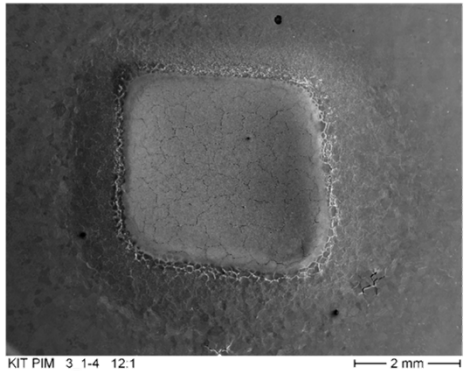
Development of new materials

…Thermal shock testing with e-beam in JUDITH-1…

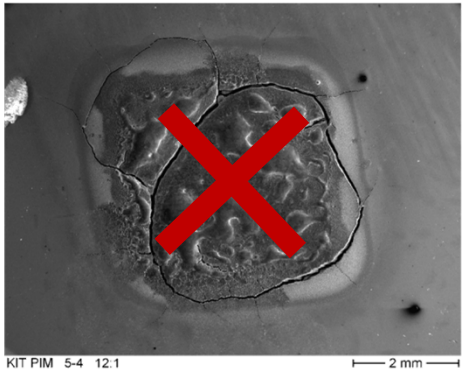
Courtesy of G. Pintsuk (FZJ)

#	T [°C]	P_{abs} [GW/m²]	Δt [ms]	E_{abs} [MJ/m²]	FHF [MW/m²*s$^{1/2}$]	# shots
D	1000	1.18	5	5.67	80	100

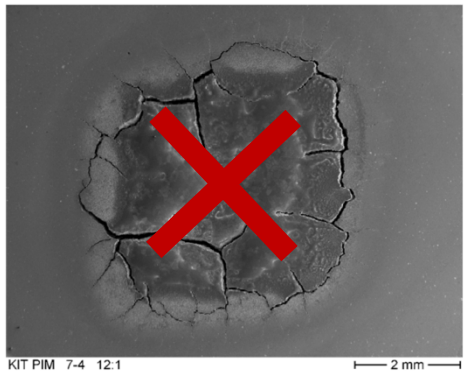
pure W



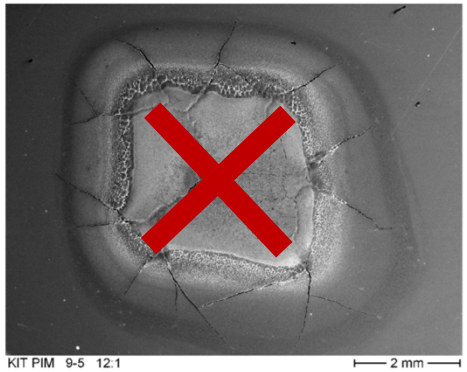
W-2Y_2O_3



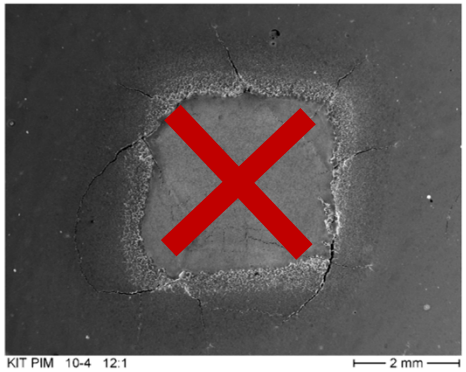
W-2La_2O_3



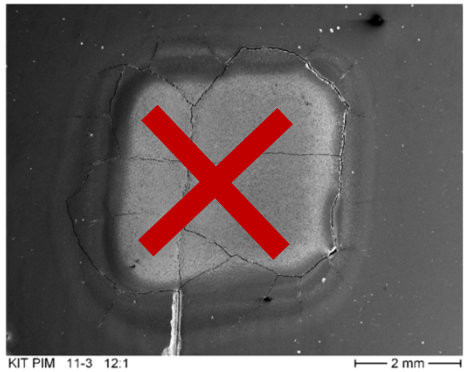
W-1TiC



W-2TaC



W-8TaC



Development of new materials

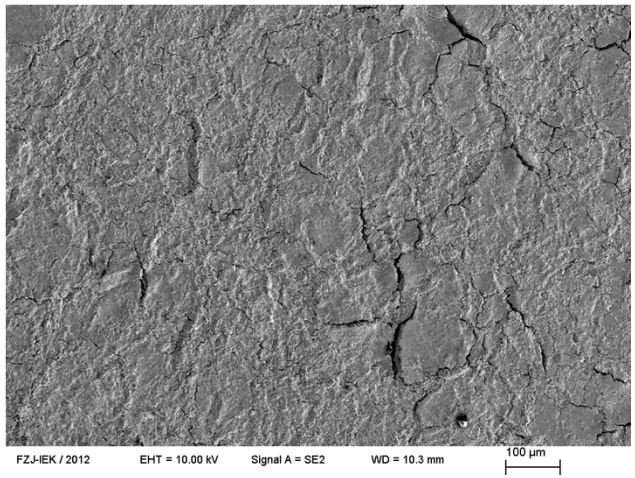
…Thermal shock testing with e-beam in JUDITH-1…

Courtesy of G. Pintsuk (FZJ)

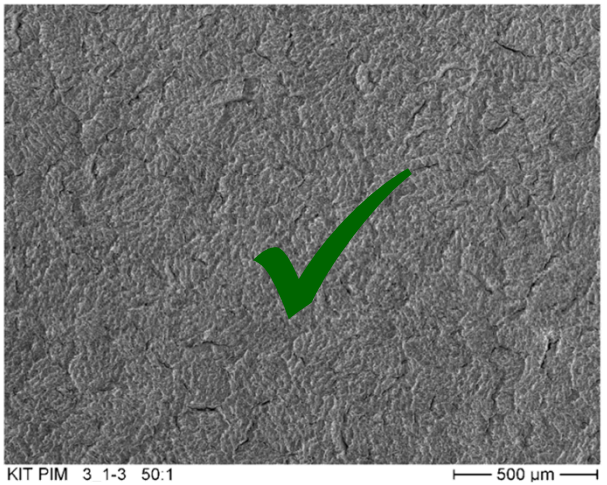
#	T [°C]	P_{abs} [GW/m^2]	Δt [ms]	E_{abs} [MJ/m^2]	FHF [MW/m^2*s$^{1/2}$]	# shots
C	1000	0.38	1	0.38	12	1000

Reference

single forged pure W



pure PIM W



Development of new materials

…HHF loading with H particles in GLADIS…

Max-Planck-Institut für Plasmaphysik

Karlsruhe Institute of Technology

Courtesy of H. Greuner (IPP)

Garching **LA**rge **D**ivertor **S**ample test facility (GLADIS) at IPP offers 2 MW neutral beams for homogeneous heating of plasma facing components at heat fluxes up to 90 MW/m² and 45 s pulse length *H. Greuner et al. / Journal of Nuclear Materials 367–370 (2007) 1444–1448*

Aims HHF tests of pure PIM W mock-ups:

➔ study of themomechanical behaviour

- temporal surface temperature evolution during screen and cycling

➔ study of surface morphology changes due to high temperature and high H fluxes

- grain growth, porosity, surface structure

W- PIM CuCrZr mock-up

Development of new materials

…HHF loading with H particles in GLADIS…

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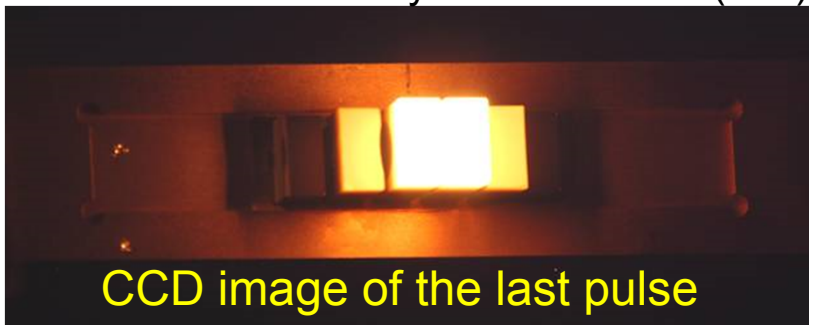


Results HHF loading in GLADIS:

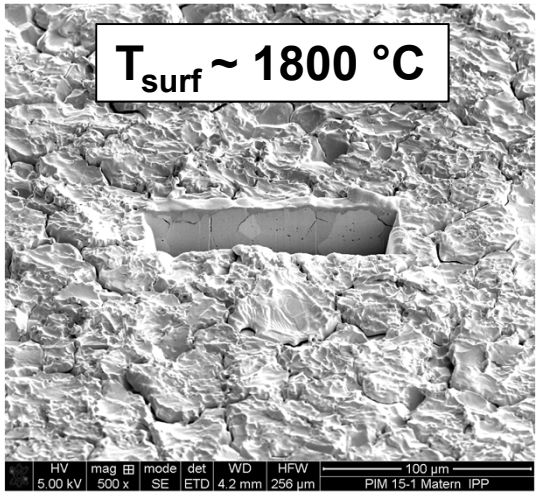
- Screening tests. 6 – 10 MW/m², 30 sec. on
- Cyclic loading: 120 cyc. 10 MW/m², 30 sec

  ➔ 1st surface analysis

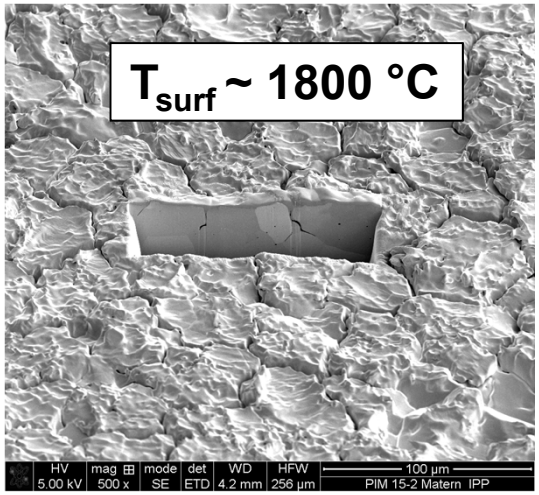
+

- Additional 120 cycles

  ➔ 2nd surface analysis



H fluence: $\Phi = 9 \cdot 10^{24}$ H/m²



H fluence: $\Phi = 18 \cdot 10^{24}$ H/m²

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Development of new materials

…HHF loading with H particles in GLADIS…

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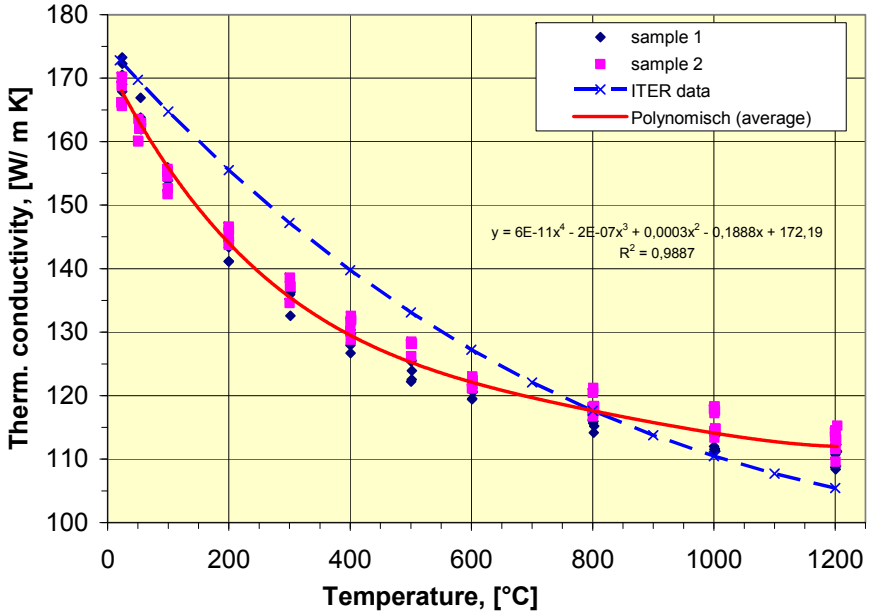
Courtesy of H. Greuner (IPP)

Results:

- The pure PIM W material showed good thermal performance, withstand w/o defects the 10 MW/m² cyclic loading
- Stable performance, no temperature increase T_{surf} during cycling
- Measurements of thermal conductivity λ confirmed the quality of the PIM process
- Pronounced grain boundary formation after loading could result in loss of grains or starting of cracks ➔ improvement of manufacturing

PIM - measurement of thermal conductivity
laser flash measurements, IPP Garching



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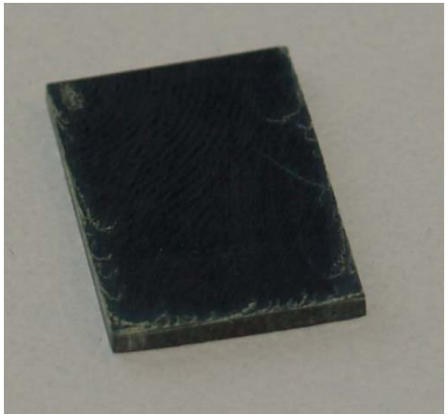
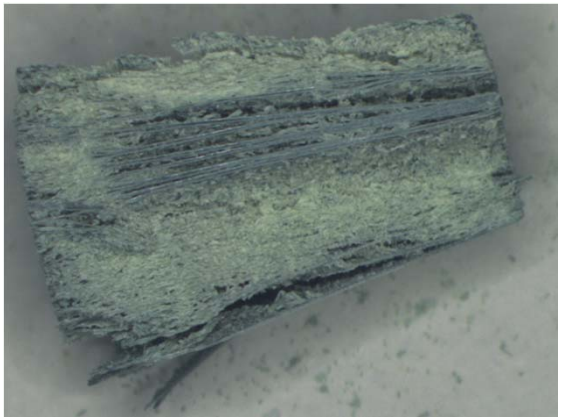
Development of new materials

…Oxidation tests on tungsten…

Pure W plate (PLANSEE material): In Oven **600 °C** – Air atmosphere



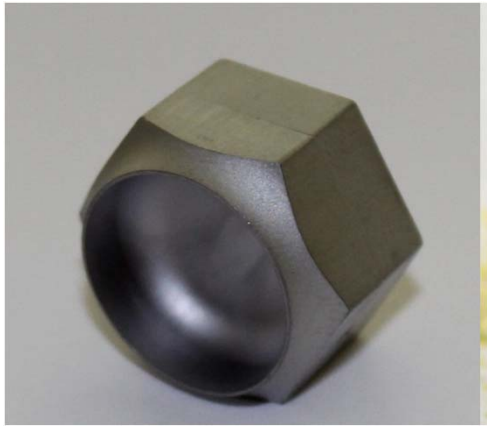
$t_{Initial}$



t = 24h

t = 48h

Pure W PIM part "tile": In Oven **700 °C** – Air atmosphere



$t_{Initial}$

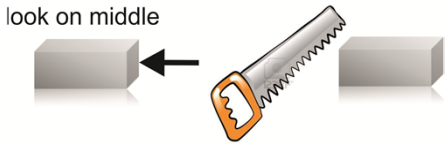
after **4 days**

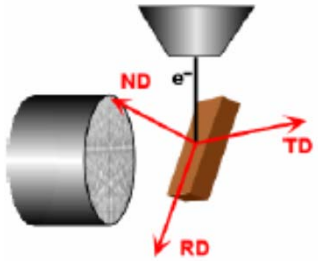
Courtesy of L. Commin (KIT)

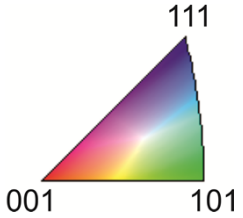
Development of new materials

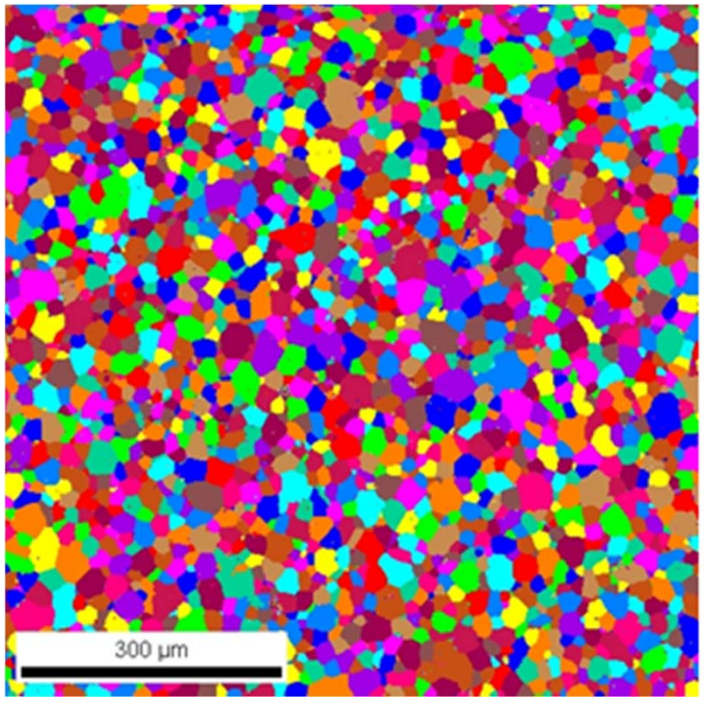
…Texture analysis: EBSD…

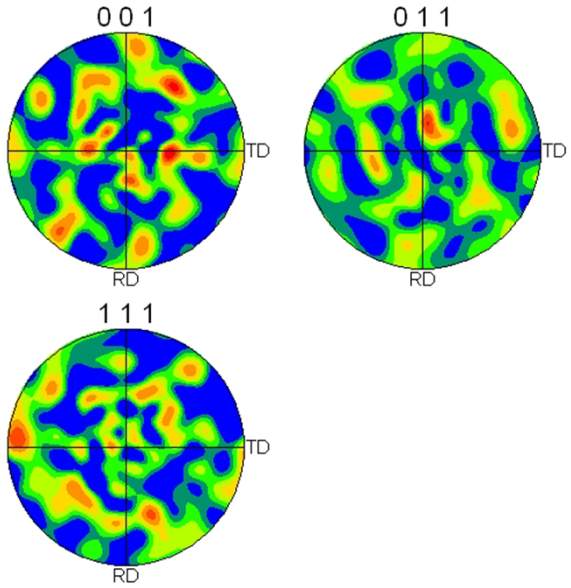
pure PIM W











Courtesy of PLANSEE SE and Oxford Materials

Outline

- Powder Injection Molding @ KIT
- Mass production of tungsten parts
- Powder Injection Molding as joining process
- Development of new materials

Summary

Summary

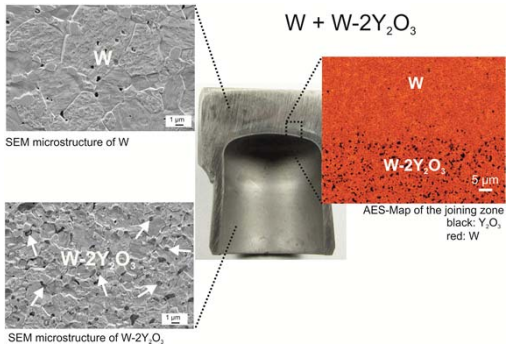
Tungsten Powder Injection Molding @ KIT Karlsruhe Institute of Technology

Mass production of components

Time & cost effective
near-net-shape forming process

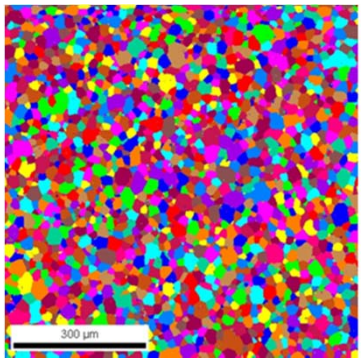
Shape complexity &
high final density

Joining technique



Joining without
brazing or welding

Material development



Create new materials
&
Investigation of properties

CCFE CULHAM CENTRE FOR FUSION ENERGY

UNIVERSITY OF OXFORD

OxfordMaterials

KIT Karlsruhe Institute of Technology

JÜLICH FORSCHUNGSZENTRUM

PLANSEE

IPP Max-Planck-Institut für Plasmaphysik

THANK YOU VERY MUCH!

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PL FUSION

EFDA EUROPEAN FUSION DEVELOPMENT AGREEMENT