Manufacturing and Characterization of PIM-W Materials as PFMs

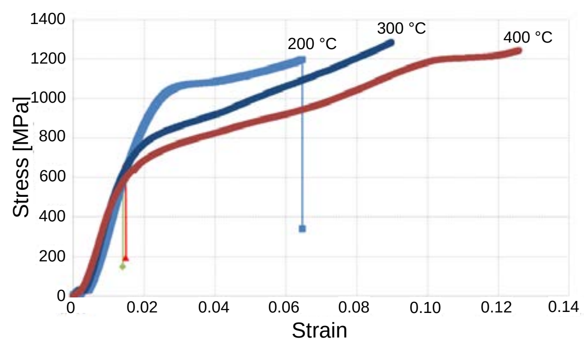
Gerald Pintsuk[1], Steffen Antusch[2], M. Rieth[2], M. Wirtz[1]

[1] Forschungszentrum Juelich (FZJ)
[2] Karsruhe Institute of Technology (KIT)

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement number 633053.
The views and opinions expressed herein do not necessarily reflect those of the European Commission.

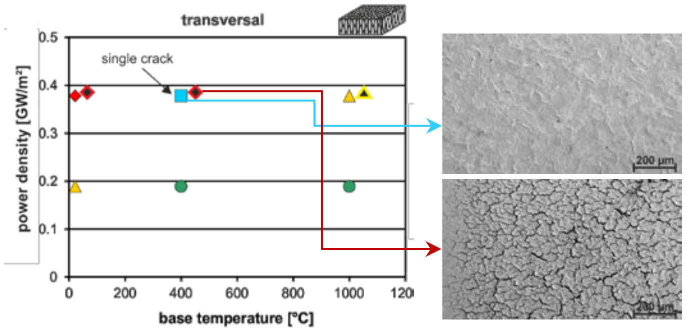
Motivation

❖ DEMO divertor development within the **EUROFusion** program **WPMAT**



❖ **Pure and particle strengthened materials** interesting characteristics: *strength, fracture toughness, ductility, recrystallization resistance*, and *sufficiently high thermal conductivity*

❖ **PIM:** *near net shape technology*; materials with *isotropic microstructure* and *properties*; *fast screening* of different compositions



❖ **Qualification** via e-beam testing (standardized method) *vs. a reference W-grade*

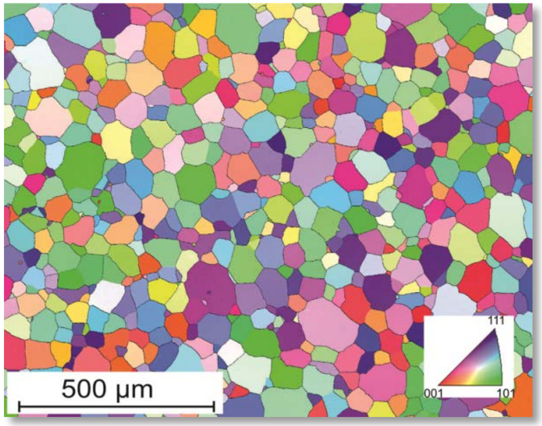
Tungsten Powder Injection Molding @ KIT

Mass production of components

Time & cost effective
near-net-shape forming process

Shape complexity & high final density

Materials development



Tailoring new materials
&
Investigation of properties

Mass production of tungsten parts

Powder

Binder

Mixing /
Kneading /
Extrusion

Feedstock

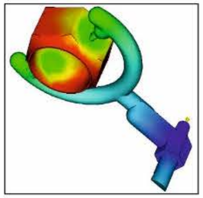
Mass production of tungsten parts

Powder

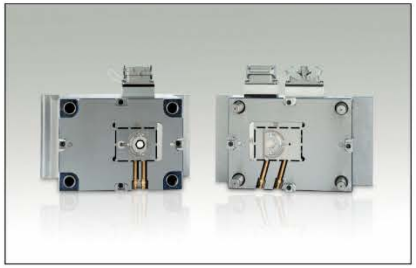
Binder

Mixing /
Kneading /
Extrusion

Feedstock



Filling simulation



PIM-tool

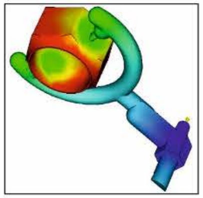
Mass production of tungsten parts

Powder

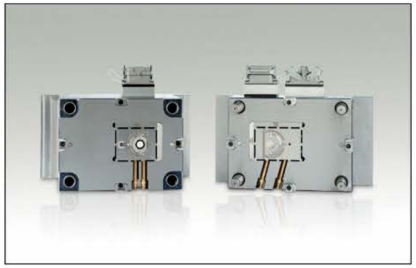
Binder

Mixing /
Kneading /
Extrusion

Feedstock



Filling simulation



PIM-tool

Injection molding of green parts

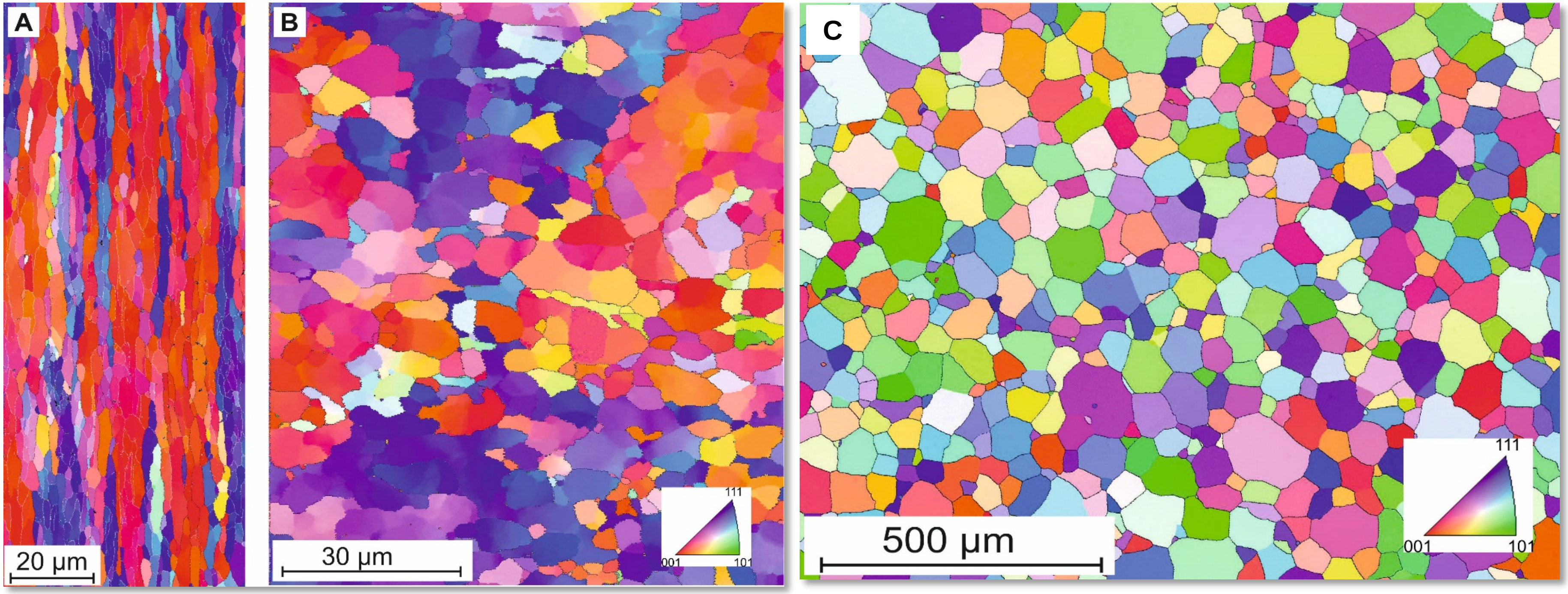
Debinding /
Heat-treatment

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

Development of new materials

Texture analysis: EBSD

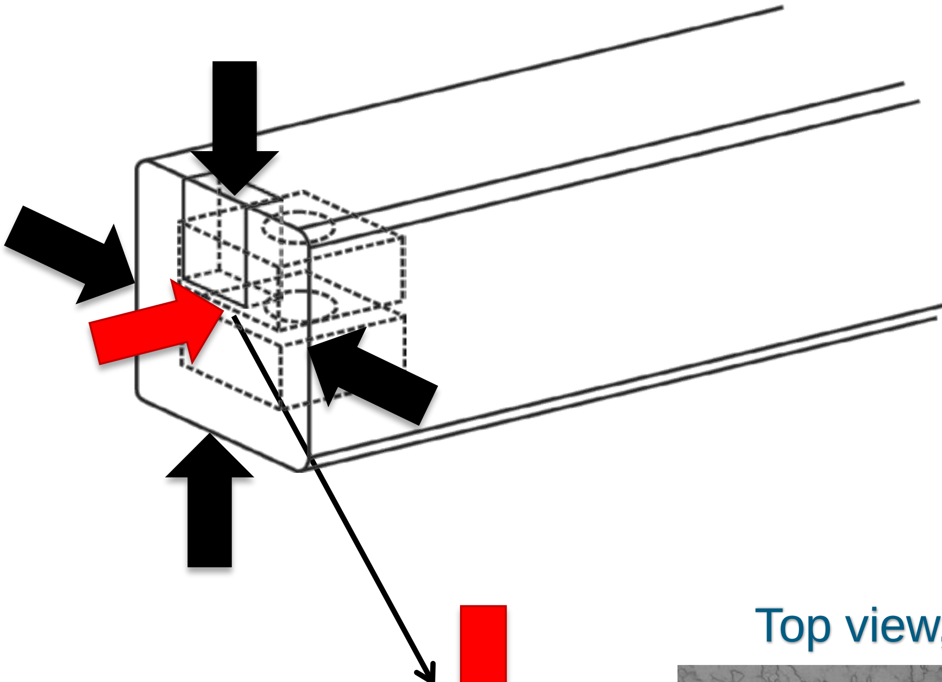
Rolled W-plate (Plansee AG) vs. PIM-W

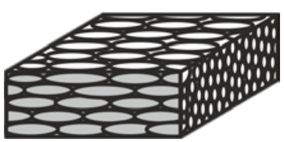


Rolled-W: **[A]** *in rolling direction – e.g. high strength and bending toughness*
[B] *perpendicular to rolling direction*

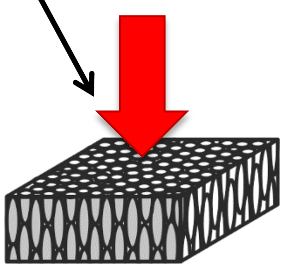
PIM-W: **[C]** *fully isotropic*

Reference W according to ITER specs („IGP“)



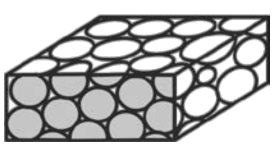


longitudinal



transversal

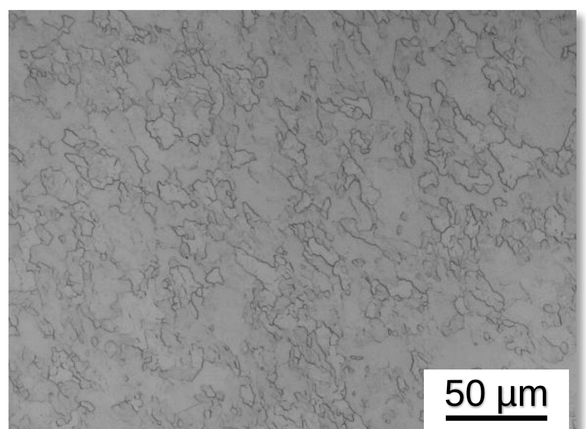
12 × 12 × 5 mm³



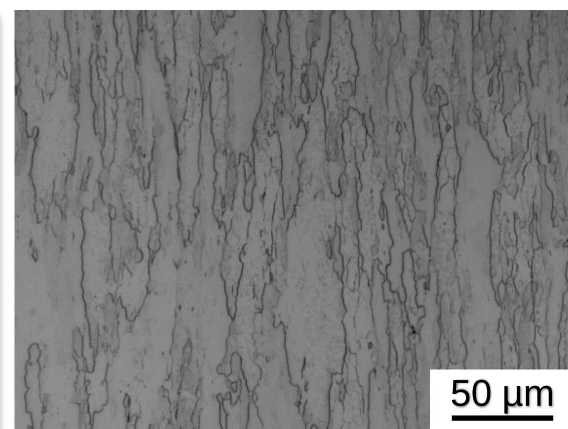
recrystallized

1600 °C, 1 hour

Top view, Ø ~10 µm



Side view, 5 × 25 µm²



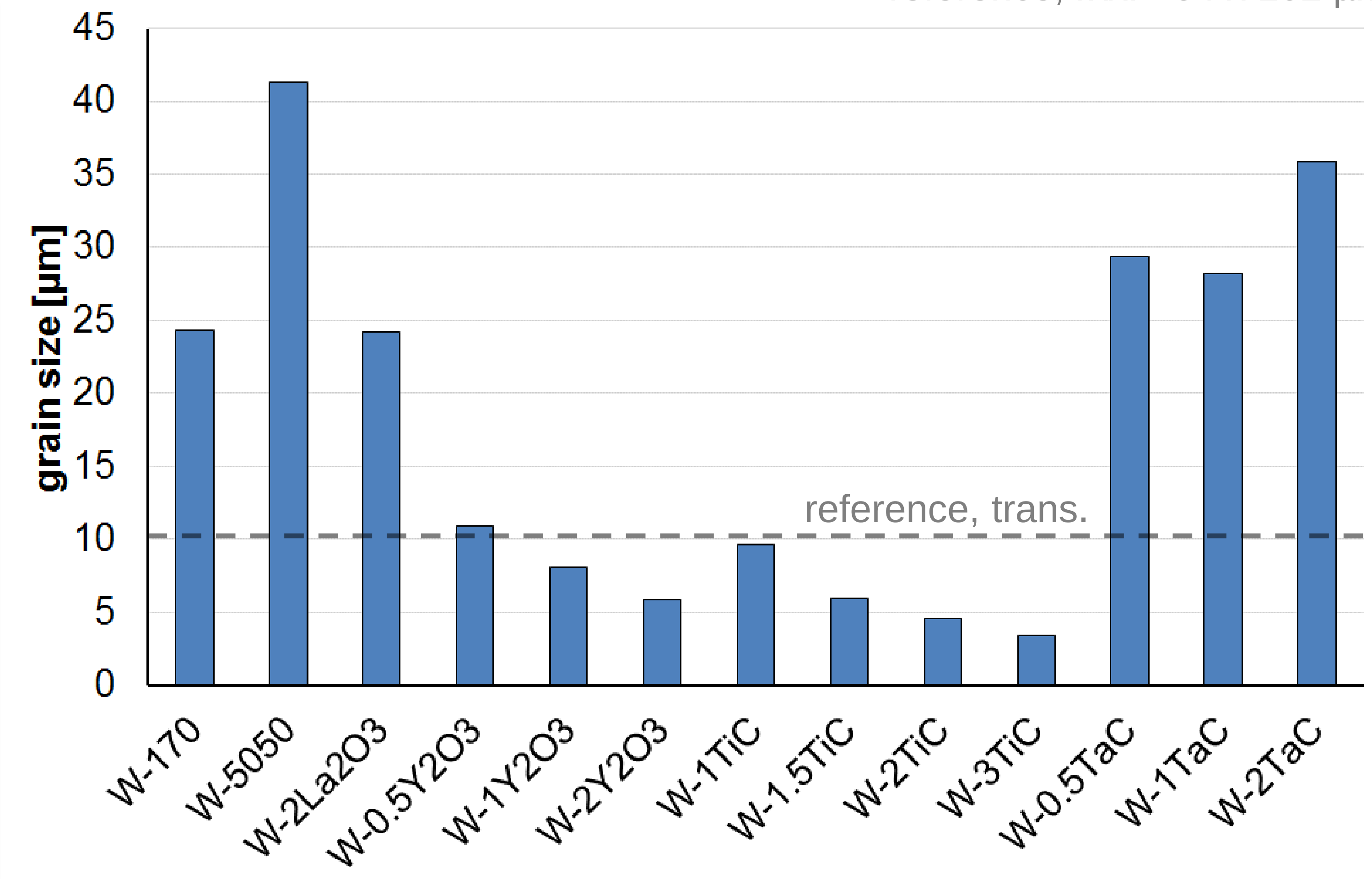
PIM: Investigated W materials

Manufacturing according to shown PIM-process; final sintering at **2400 °C; particle sizes < 1 µm**

- **pure W**: 2 grades with different powder sizes (*W-170, W-5050*)
- **W-2La_2O_3**: initial composition; vaporization of La_2O_3 during sintering $\Rightarrow$ pure W with "clean" grain boundaries
- **W-Y_2O_3**: 3 grades with different Y_2O_3 content (*W-0.5Y_2O_3, W-1Y_2O_3, W-2Y_2O_3*)
- **W-TiC**: 4 grades with different TiC content (*W-1TiC, W-1.5TiC, W-2TiC, W-3TiC*)
- **W-TaC**: 3 grades with different TaC content (*W-0.5TaC, W-1TaC, W-2TaC*)

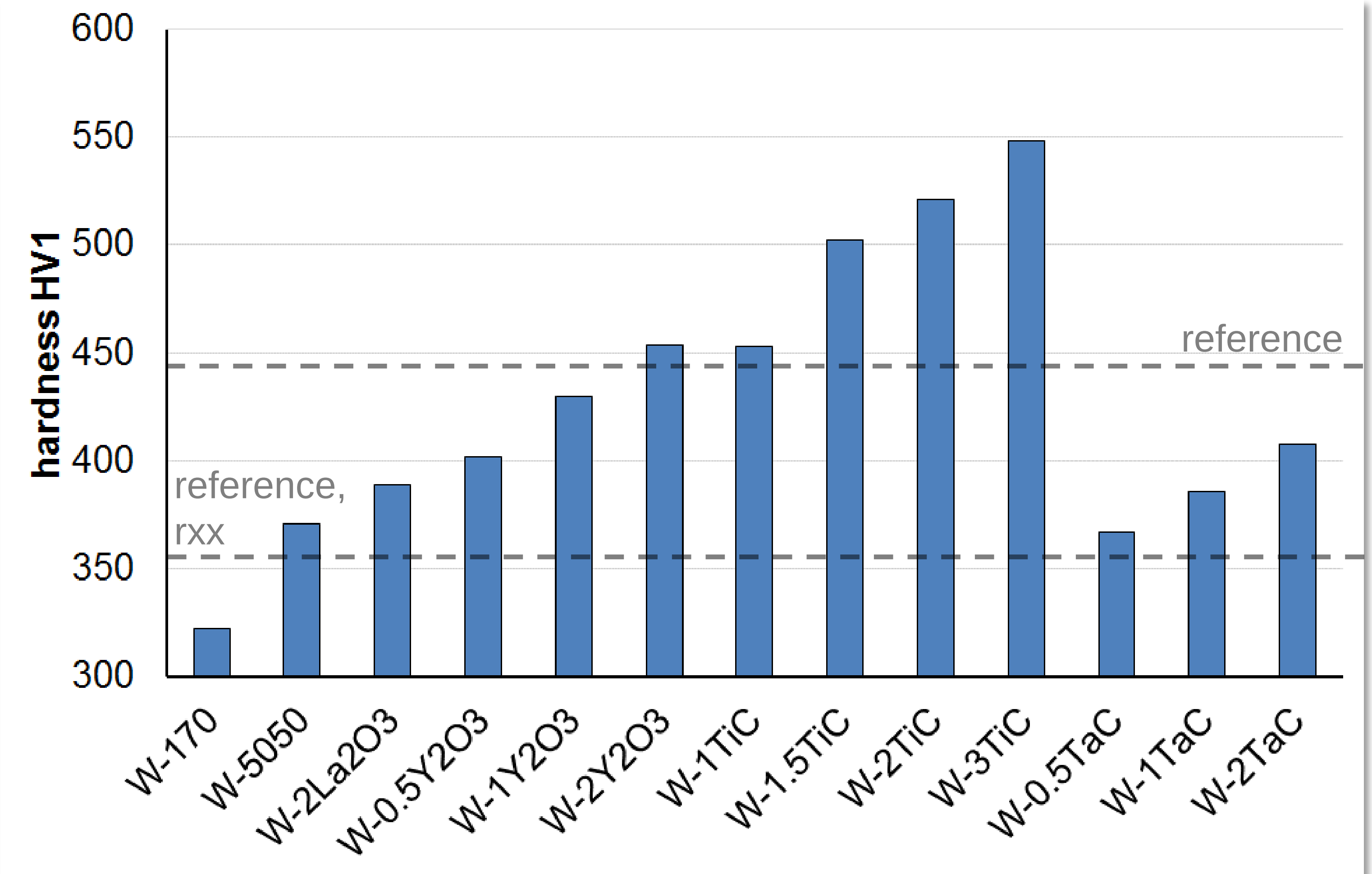
Materials grain size

reference, long.: 10 x 25 µm
reference, rxx: 64 x 102 µm



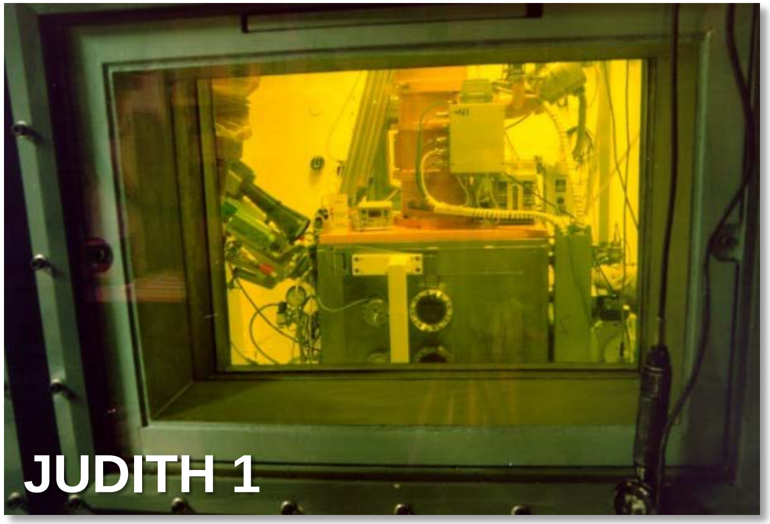
❖ Optimization potential by variation of raw materials (powder sizes)

Materials hardness



❖ Pure PIM-W similar to recrystallized W; hardness increase only for W-TiC

Qualification via thermal shock: e-beam



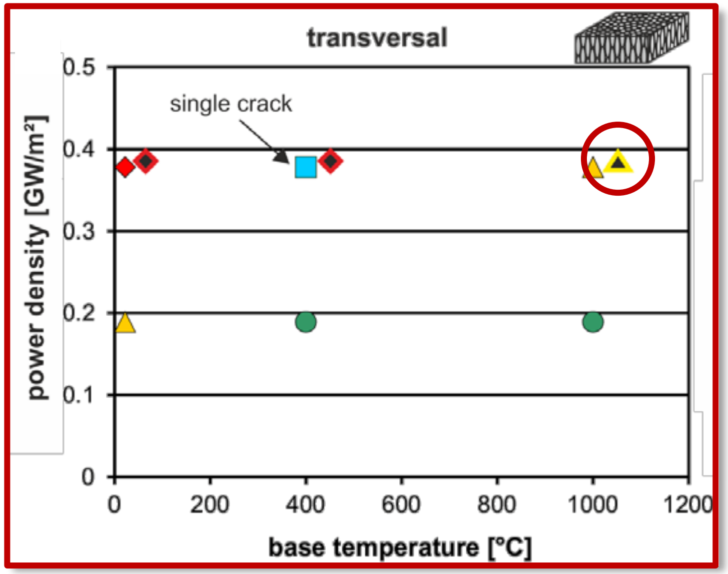
E-beam parameters

acceleration voltage:	*120 - 150 kV*
beam power:	*≤ 60 kW*
pulse length:	*1 ms – cont.*
beam diameter:	*1 mm*
scanning frequency:	*≤ 100 kHz*

Test parameters

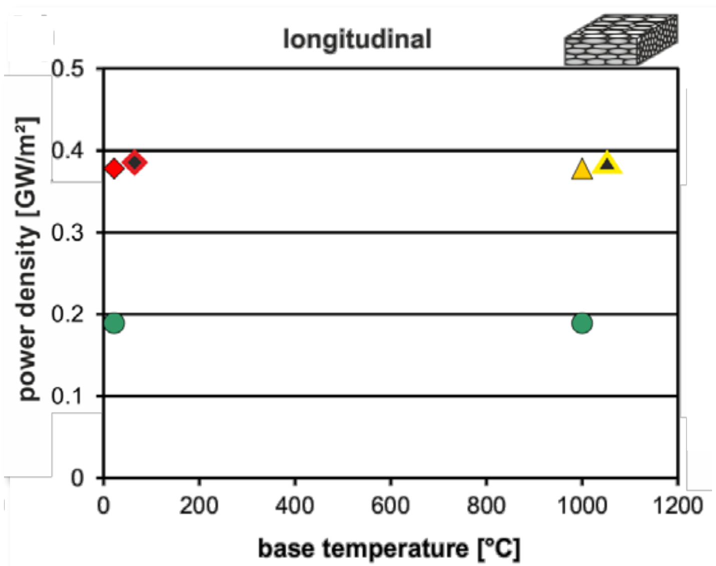
power density:	***0.19-0.38 GW/m^2***
pulse length:	***1 ms***
pulse number:	***100, 1000***
base temperature:	***RT, 400 °C, 1000 °C***

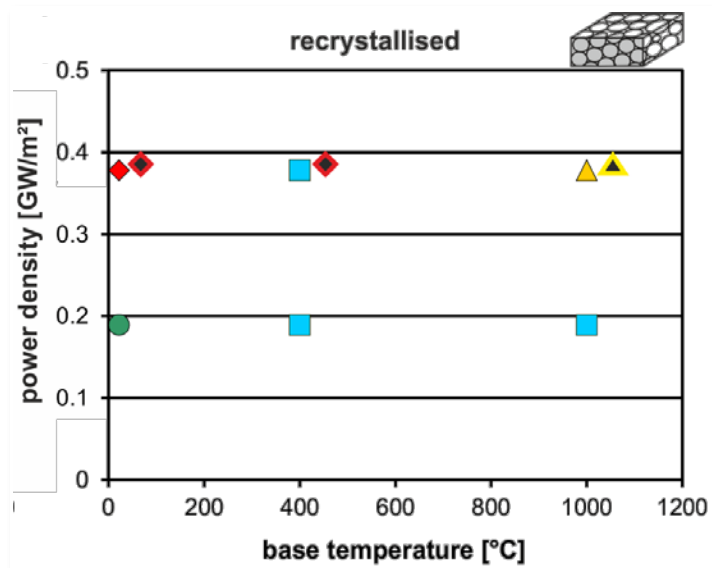
Reference W according to ITER specs („IGP“)



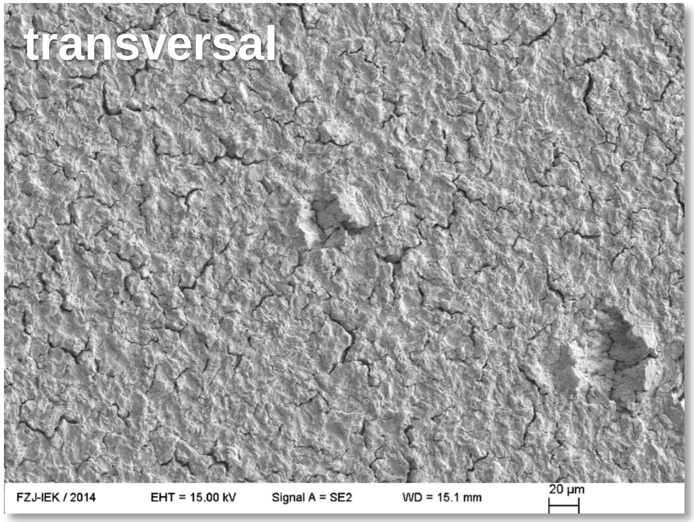
n = 100 | **n = 1000**

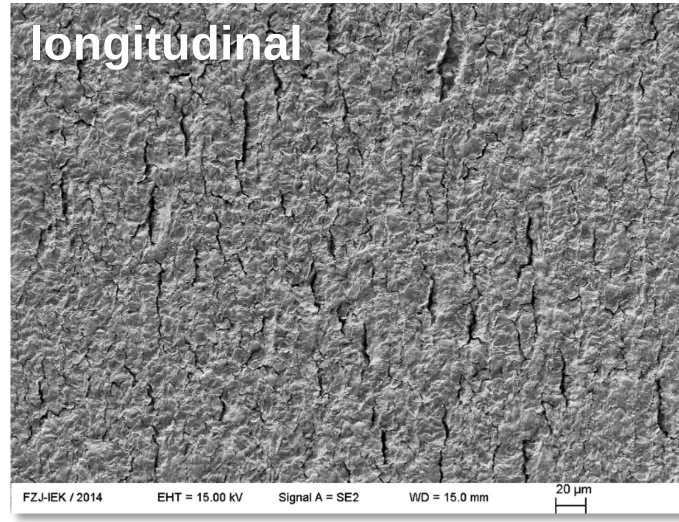
- no damage
- surface modification
- crack network | crack network
- small cracks | small cracks

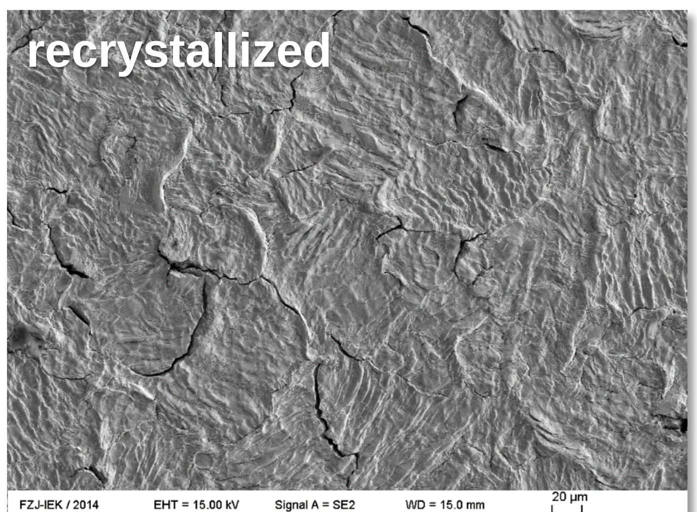




Thermal shock response: reference W

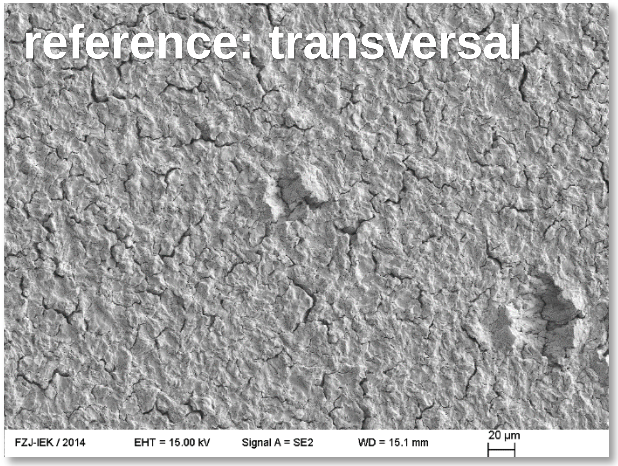


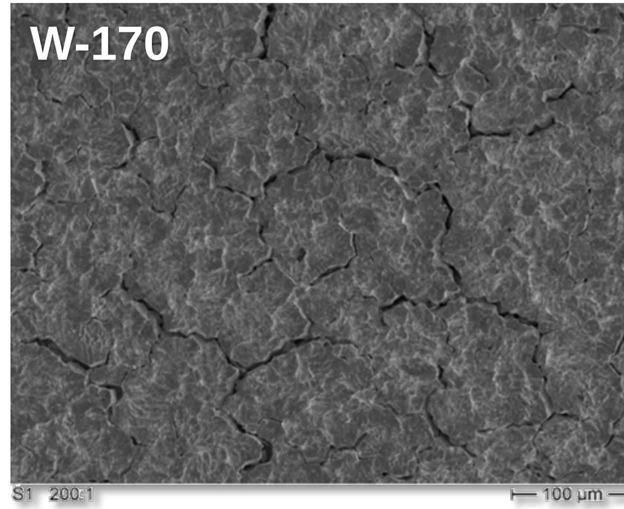


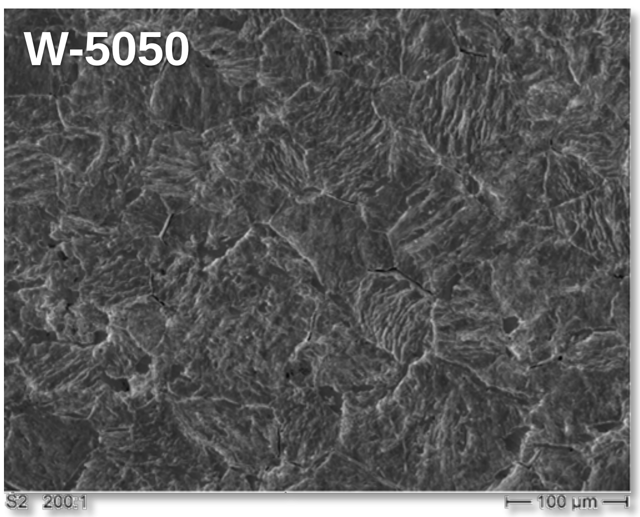


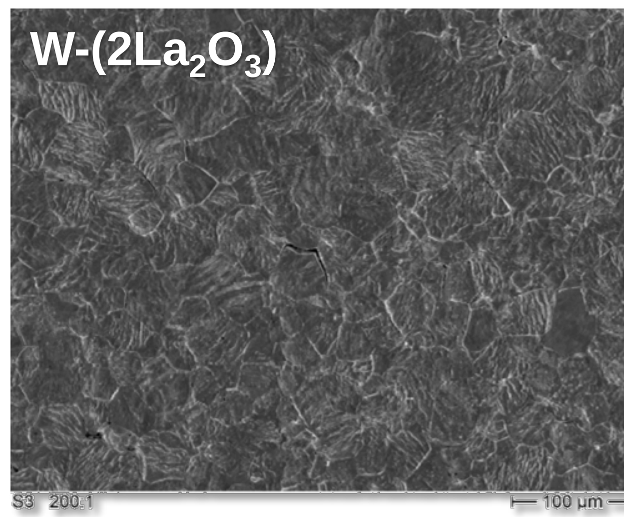
- small crack formation
- grain loss for transversal orientation
- significant surface roughening for recryst. material

ELM-test at elevated temperature



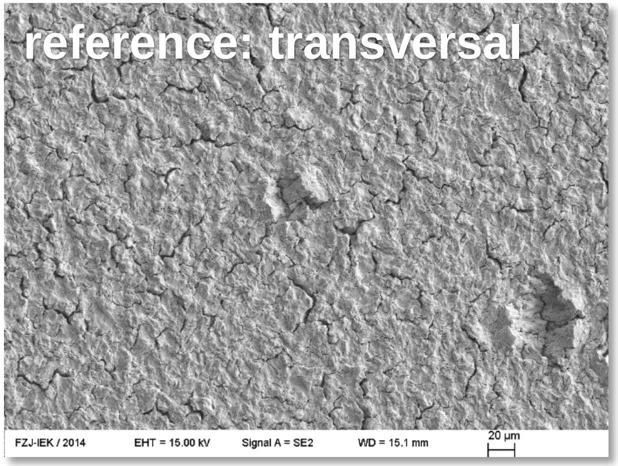


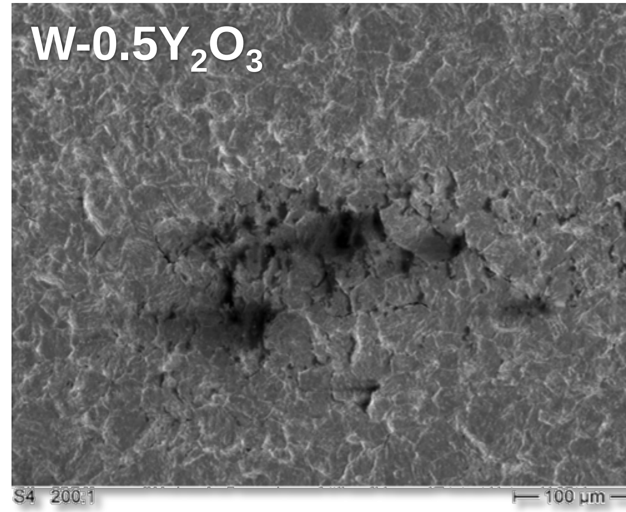


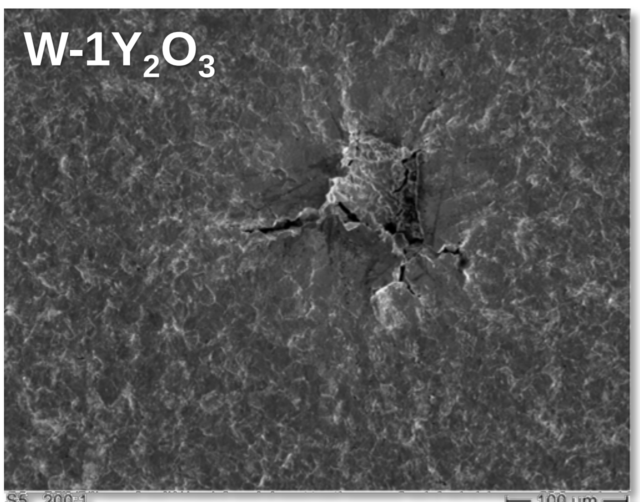


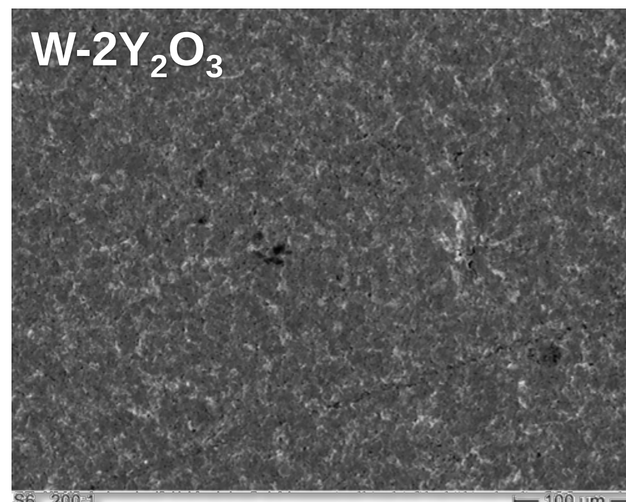
- ❖ Significant surface roughening – similar to recrystallized material!
- ❖ Reduced crack formation compared to reference

ELM-test at elevated temperature



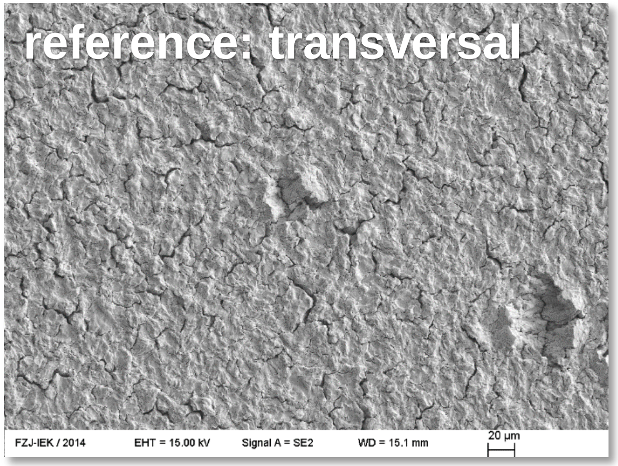


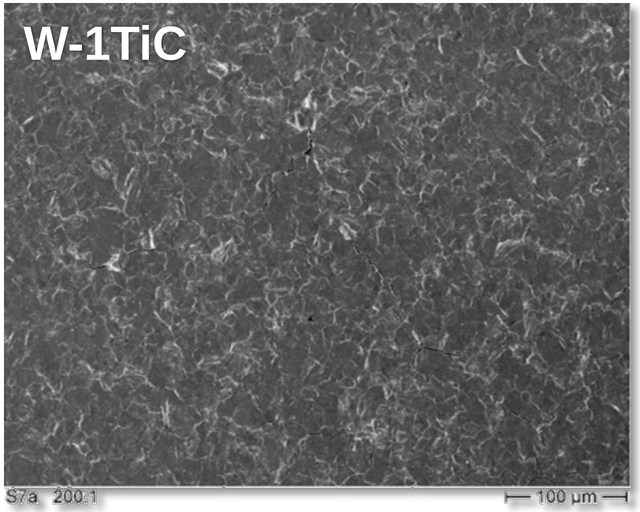


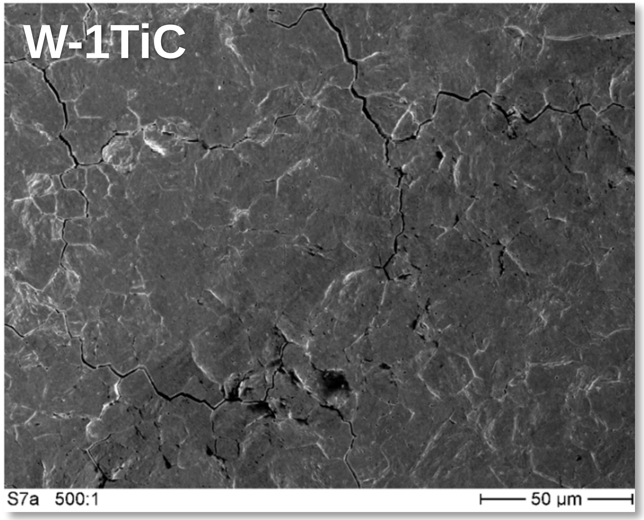


- Local µ-cracks due to inhomogeneities
- Reduced crack formation compared to reference

ELM-test at elevated temperature

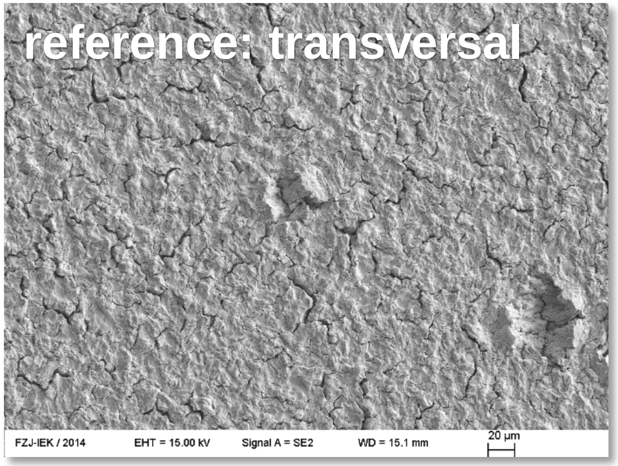


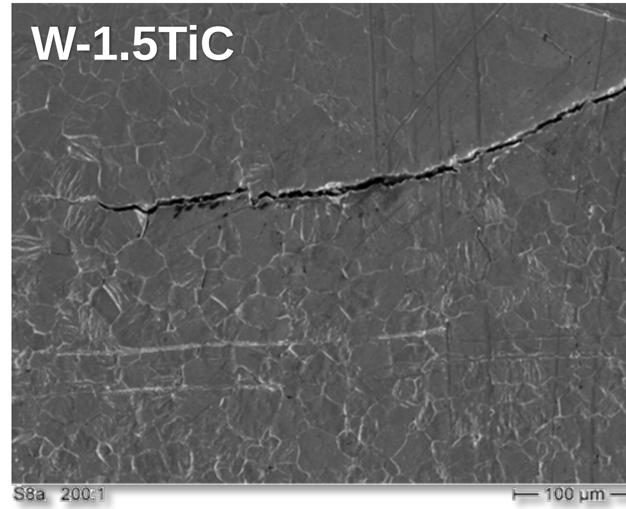


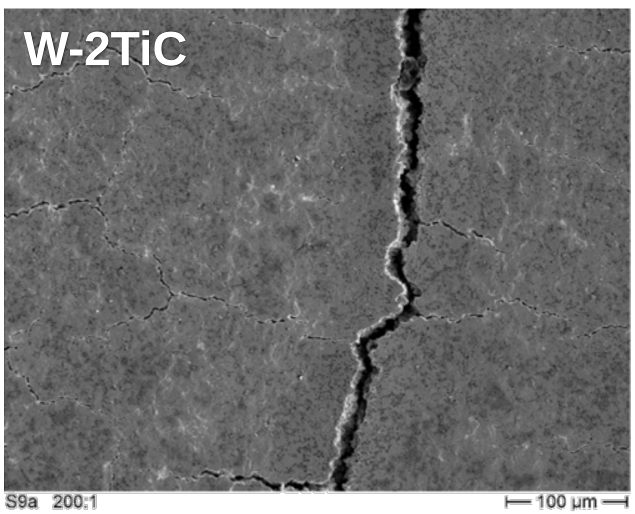


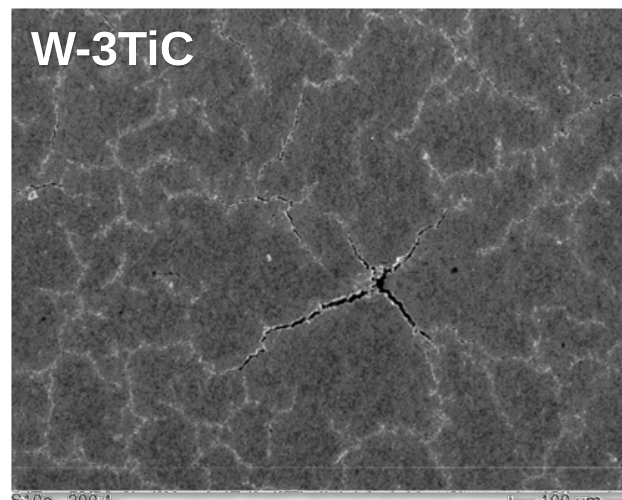
- ❖ Low surface roughening
- ❖ Crack formation similar to reference

ELM-test at elevated temperature



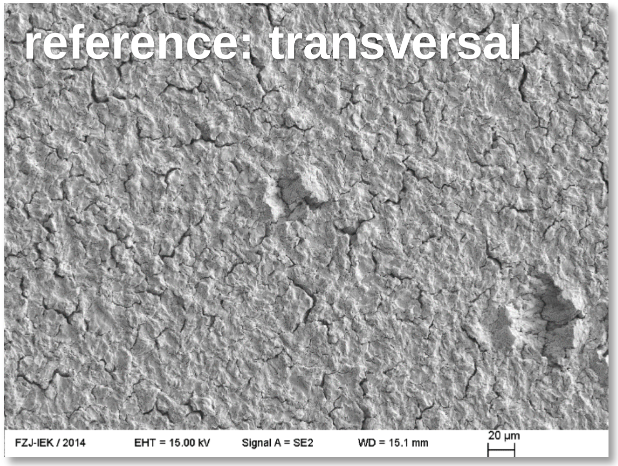


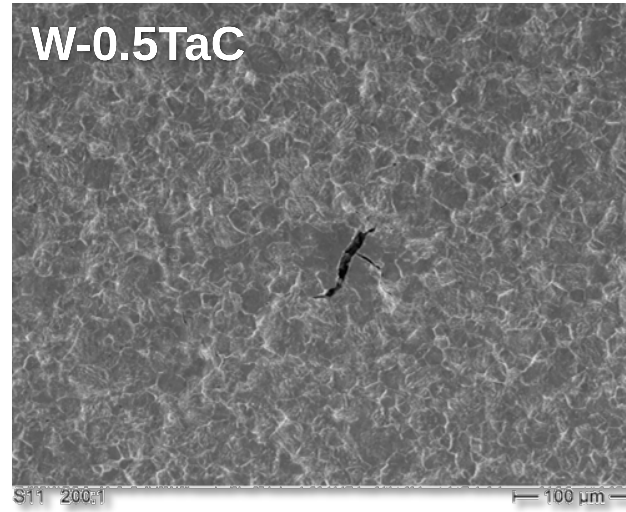


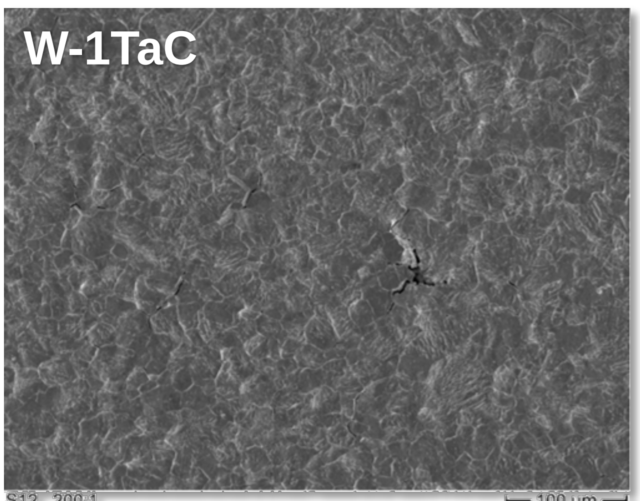


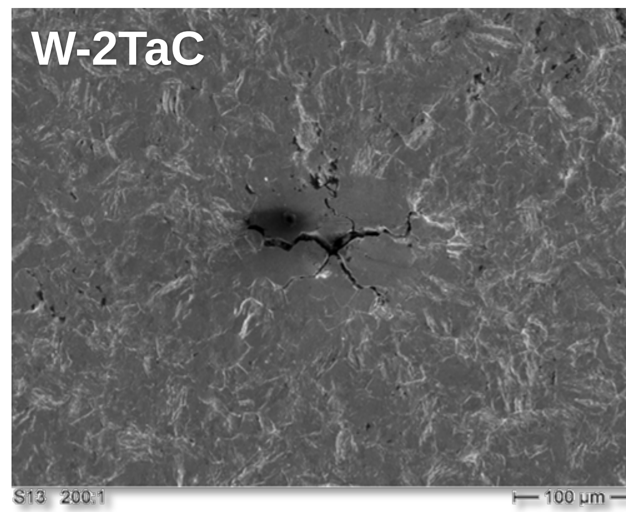
- ❖ Large crack formation
- ❖ No improvement compared to reference

ELM-test at elevated temperature





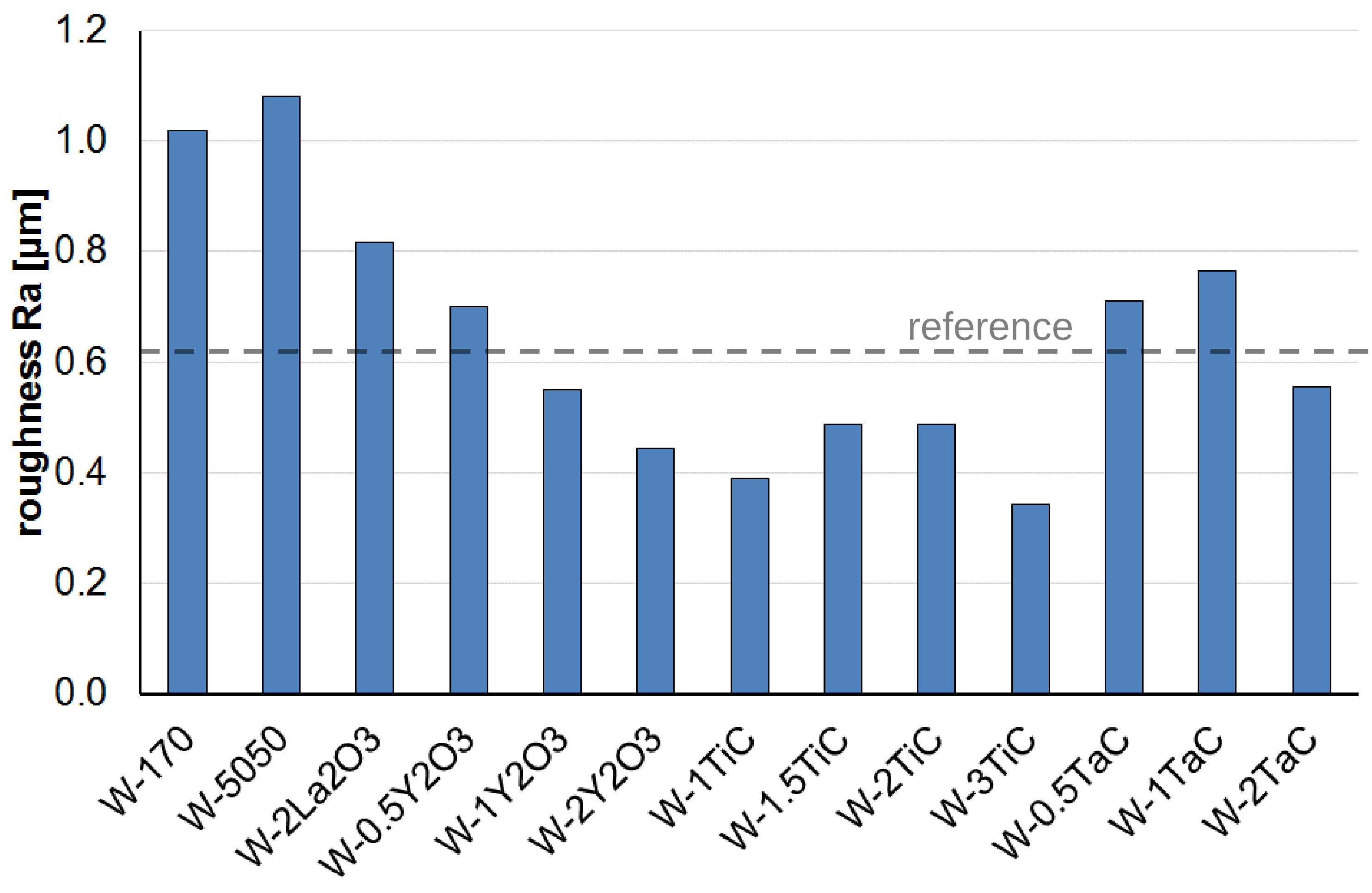




- Local µ-cracks due to inhomogeneities.
- Reduced crack formation compared to reference

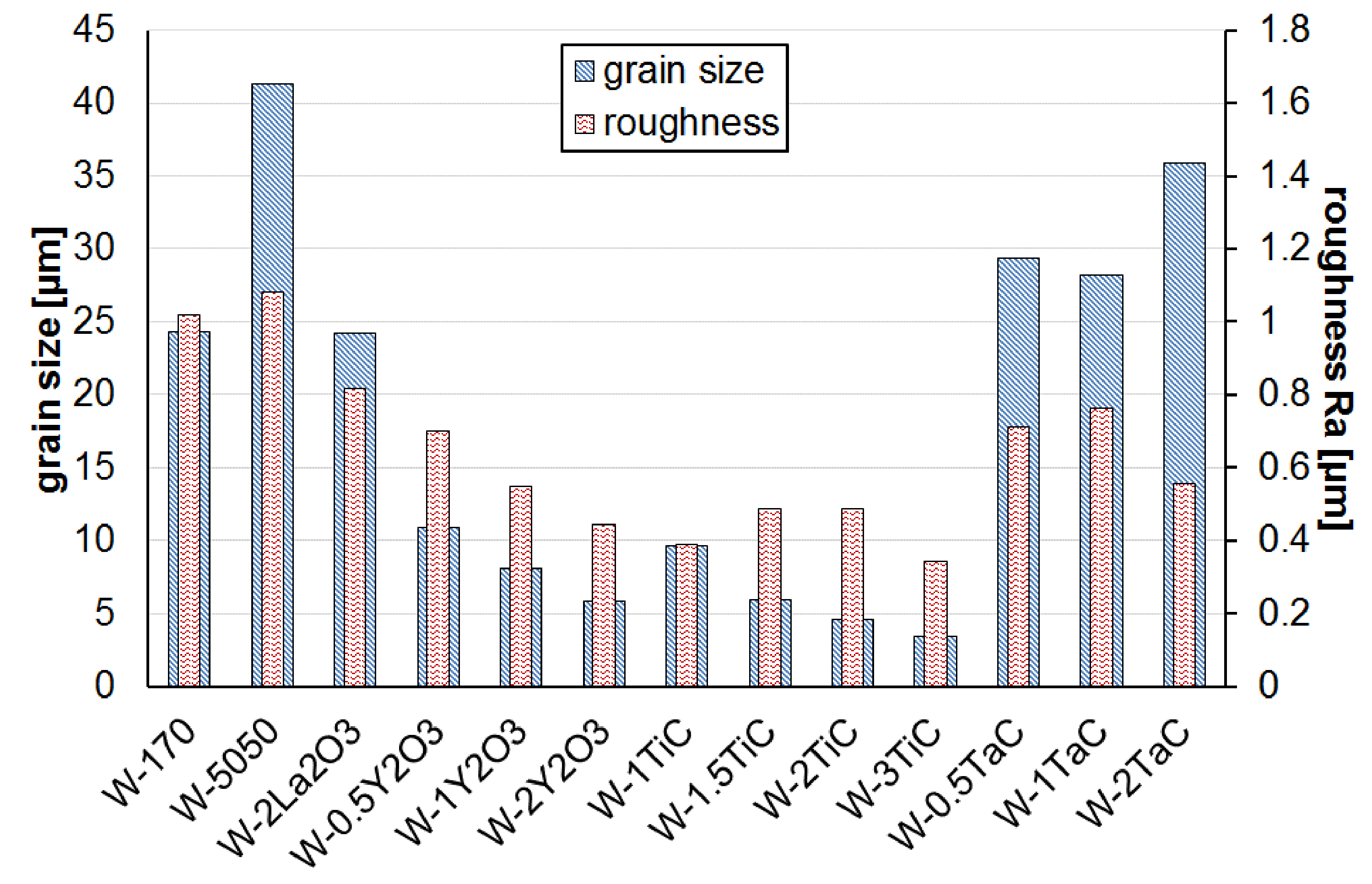
ELM-test at elevated temperature

reference, rxx: 1.33 µm



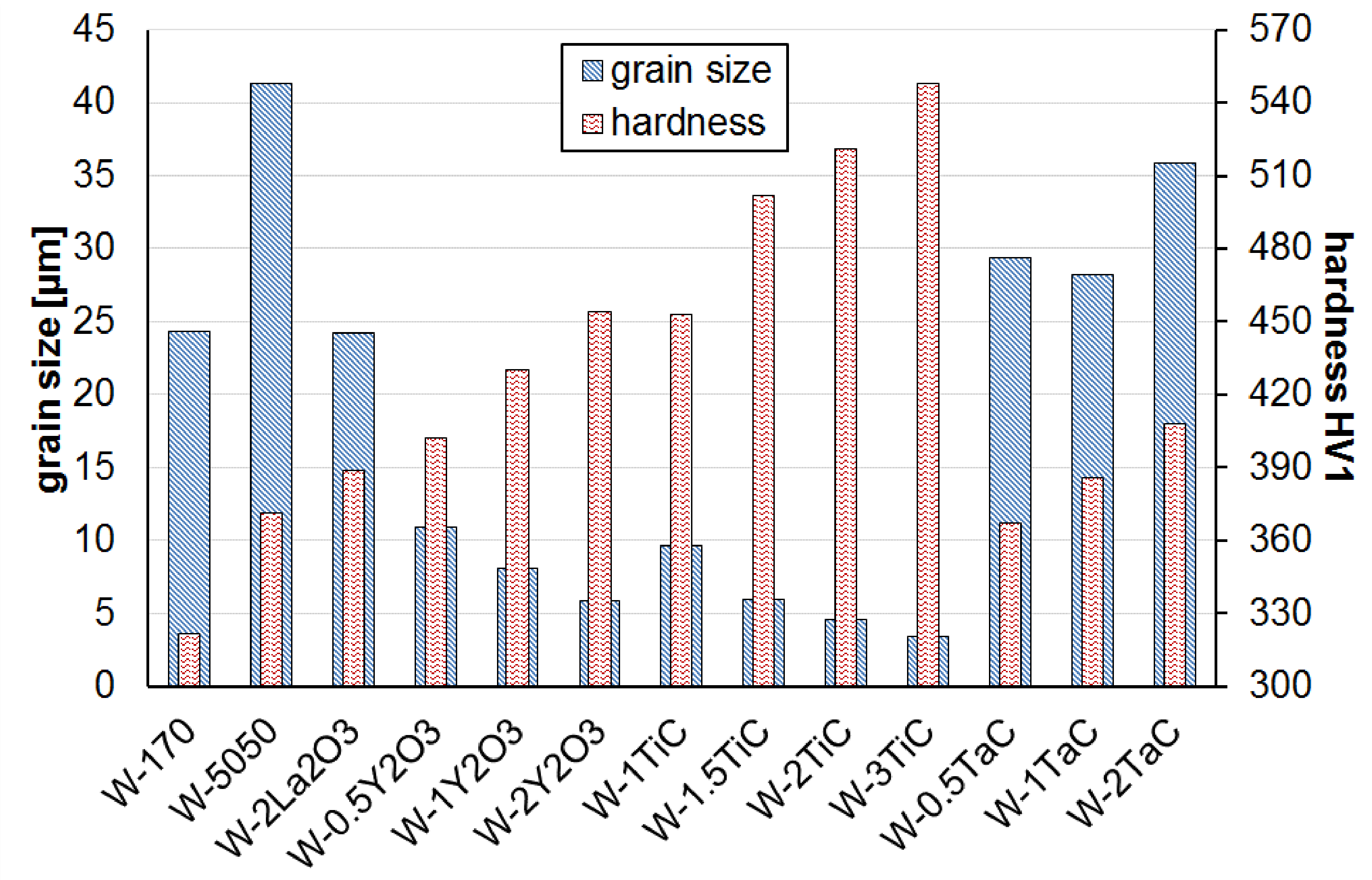
❖ Reduced roughening / plastic deformation for W-Y_2O_3 and W-TiC materials

Grain size vs. roughness



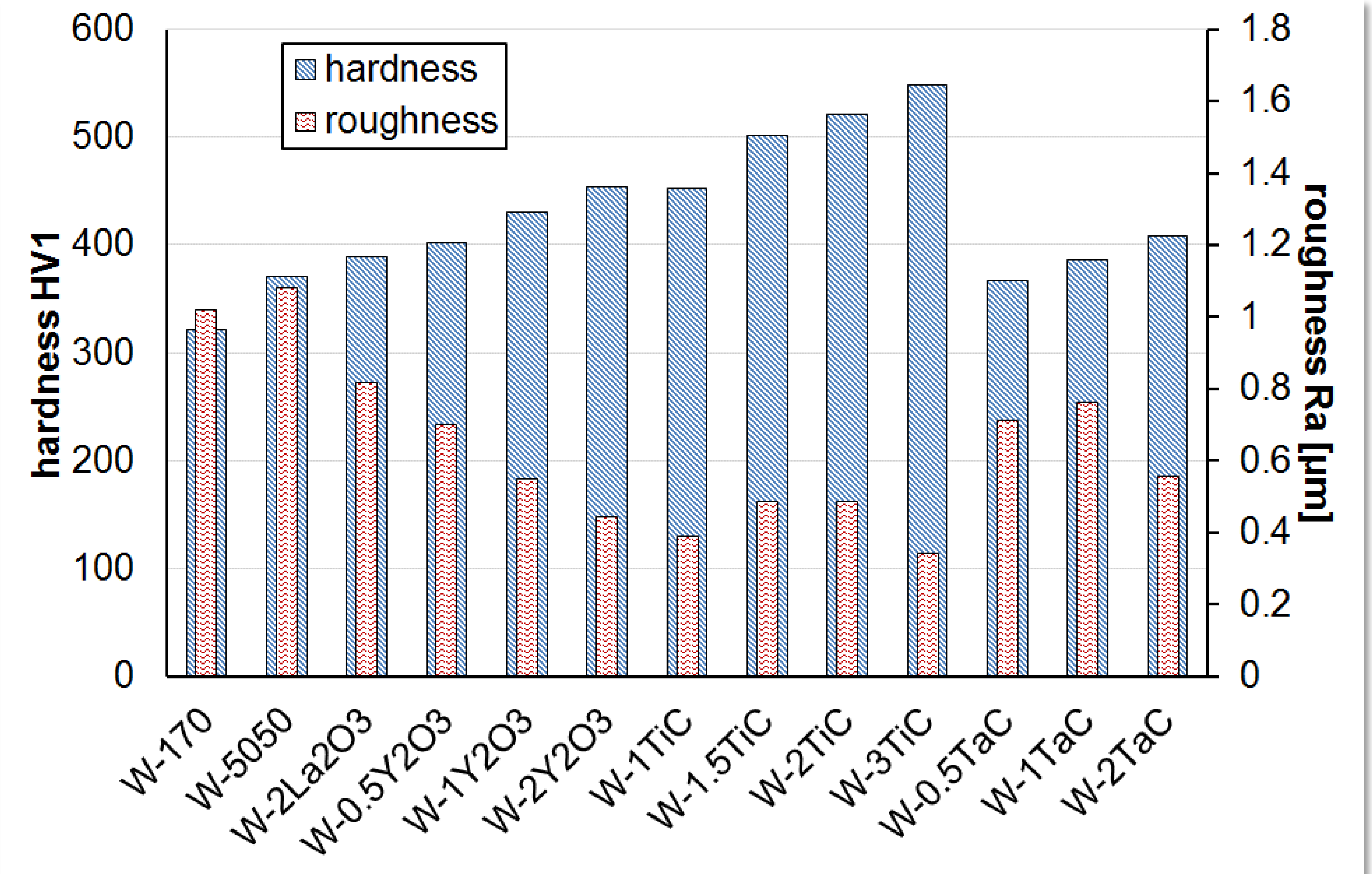
❖ Less roughening with decreasing grain size

Grain size vs. hardness



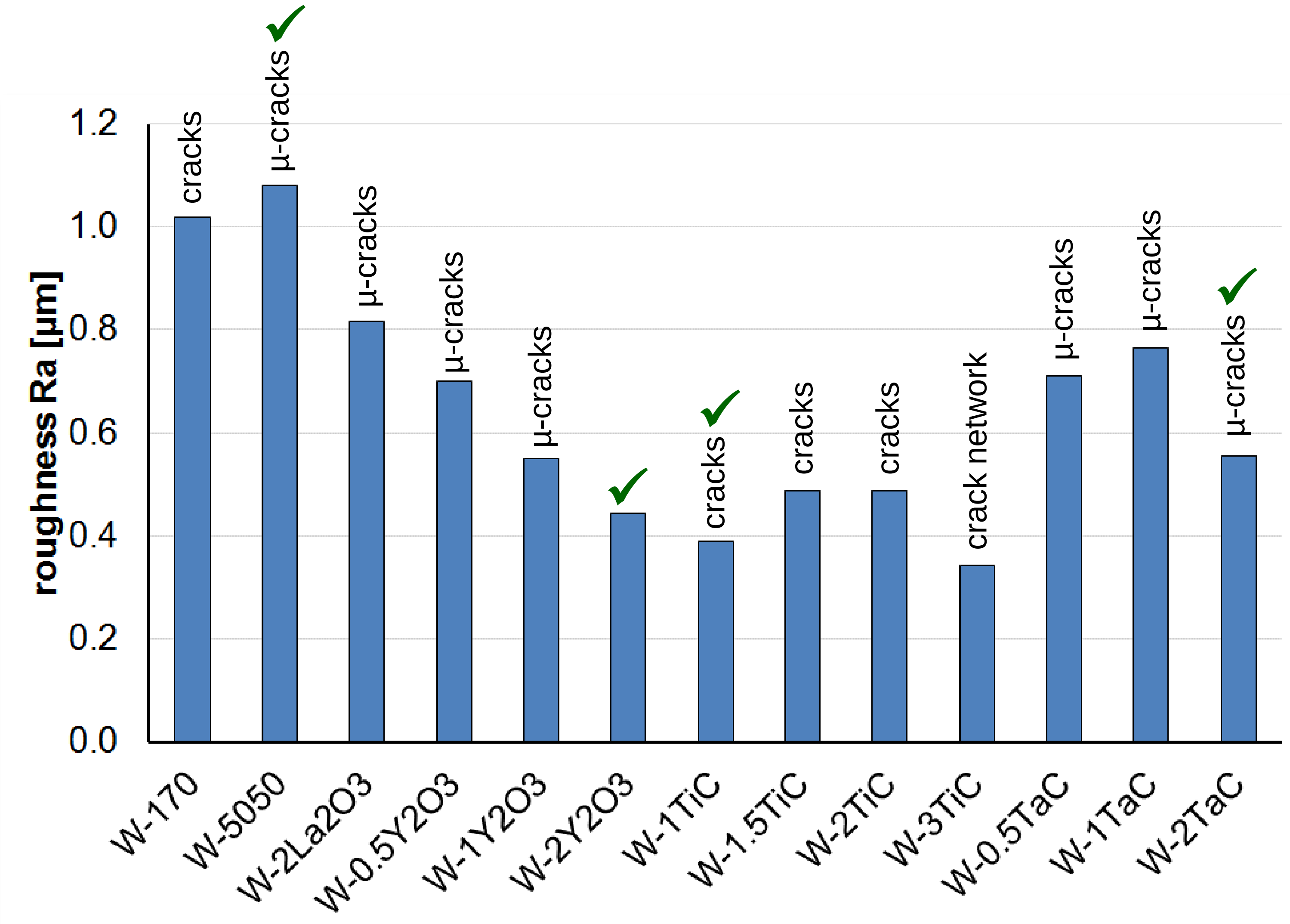
❖ Increased hardness with decreasing grain size

Hardness vs. roughness



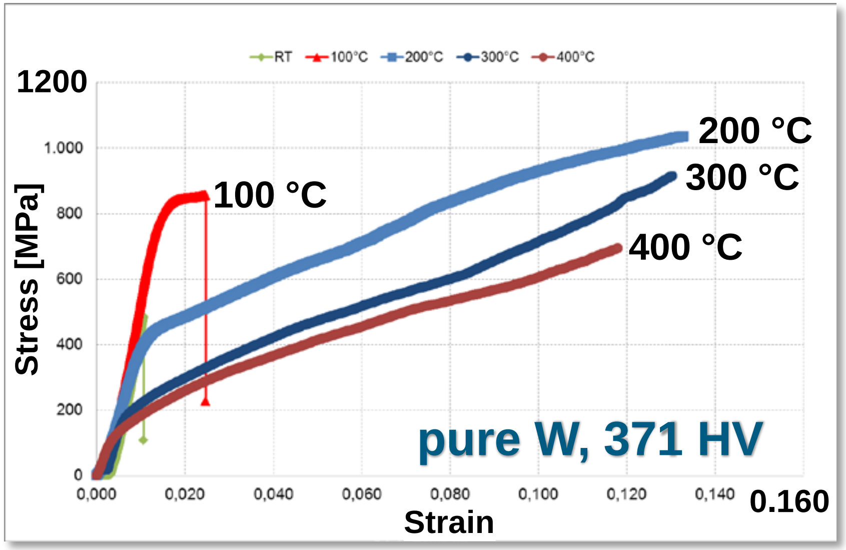
❖ Decreasing roughness with increasing hardness

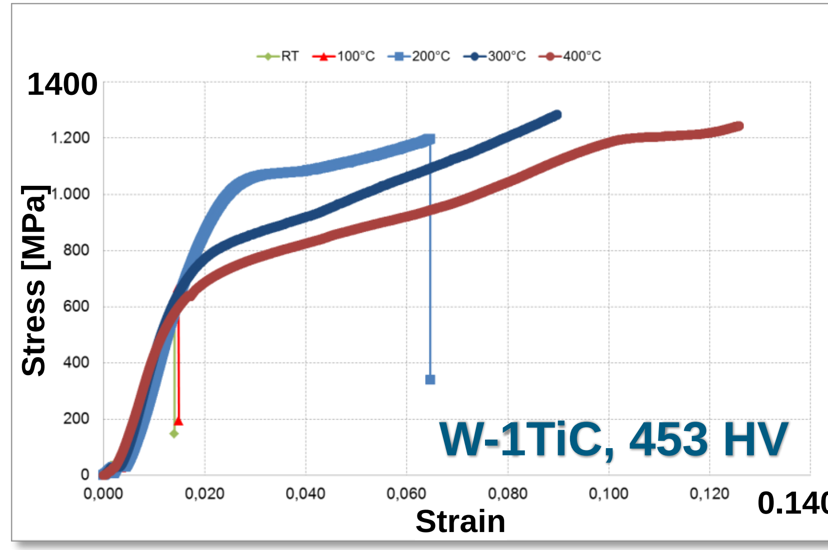
ELM-test at elevated temperature

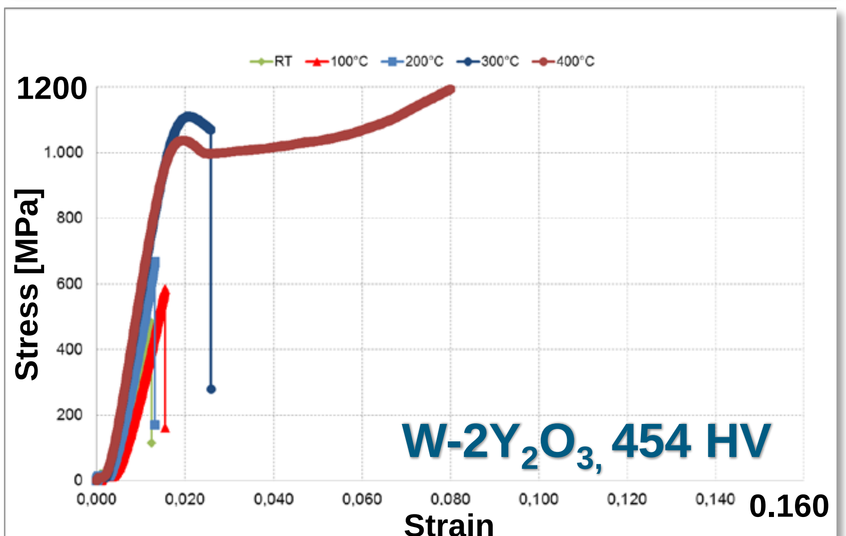


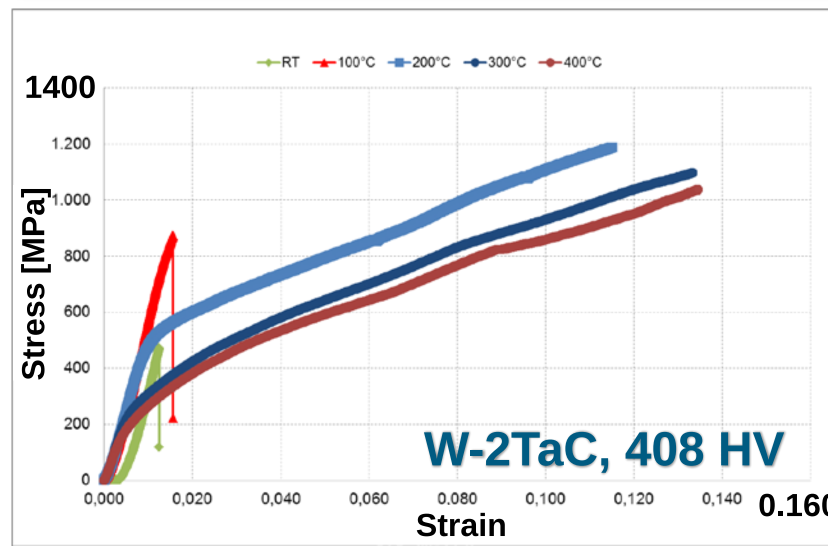
✓ Further investigation via 4pt-bending & disruption tests

Mechanical testing via 4pt-bending









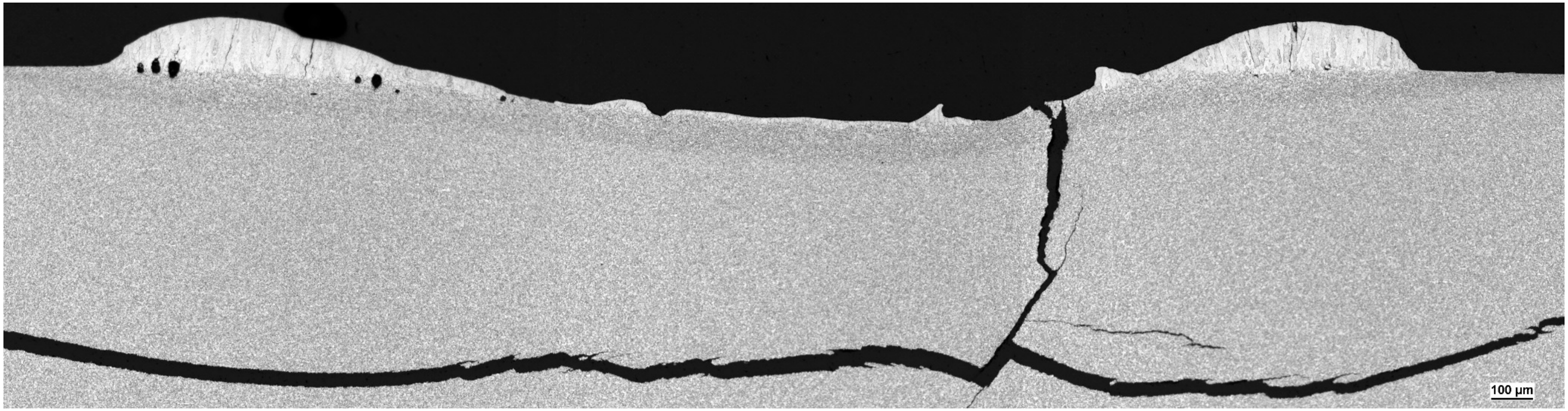
Sample geometry: *12 × 1 × 1 mm^3*

Strain rate: *0.033 mm/min*

Disruption test - Rationale

W-1.1TiC (H. Kurishita): P_{abs} = 0.38 GW/m², t = 1 ms, n = 1000, T = 1000 °C
⇒ low roughness (R_a = 0.3 µm)
⇒ only small and localized crack formation

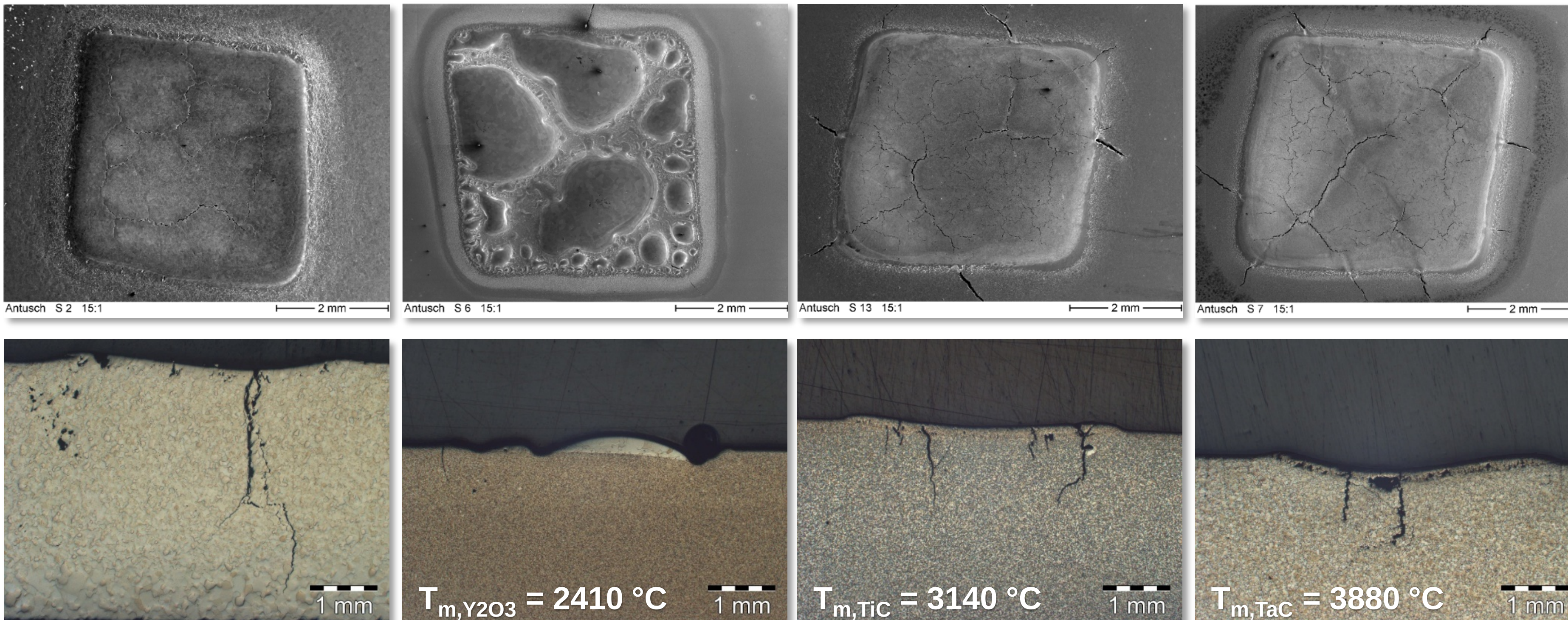
P_{abs} = 1.13 GW/m², t = 5 ms, n = 10, T = RT



No disruption on cool surface ⇒ disruption test will be done at 1000 °C!

Disruption test

W-5050	W-2Y_2O_3	W-1TiC	W-2TaC



Loading conditions:
n = 100
T = 1000 °C
Δt = 5 ms
L_{abs} = 1.13 GW/m^2

Crack formation
vs.
inhomogeneous melting!

Summary

Fabrication

- Mass production of near-net-shape parts via PIM @ KIT
- Brittle to ductile transition for ***pure PIM W*** at ***200 °C (low strain rates)***
- High density (***> 99 % T.D.***)
- Fully ***isotropic*** material properties

Qualification

- Increased hardness and mechanical strength for ***W-Y_2O_3*** and ***W-TiC*** materials ⇒ ***reduced roughening / plastic deformation***
- Reduced roughening ⇒ ***thermal fatigue*** induced crack formation (in view of > 10^6 ELM pulses) ***is slowed down***
- Disruption test: ***crack formation*** (≥ 1 mm) is still an issue even ***at 1000 °C***
- Disruption test: ***additives*** with relative ***low melting point*** may cause an ***inhomogeneous melt distribution***

JÜLICH FORSCHUNGSZENTRUM

KIT Karlsruher Institut für Technologie