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Thermal shock response of fine and ultra fine grained tungsten based materials

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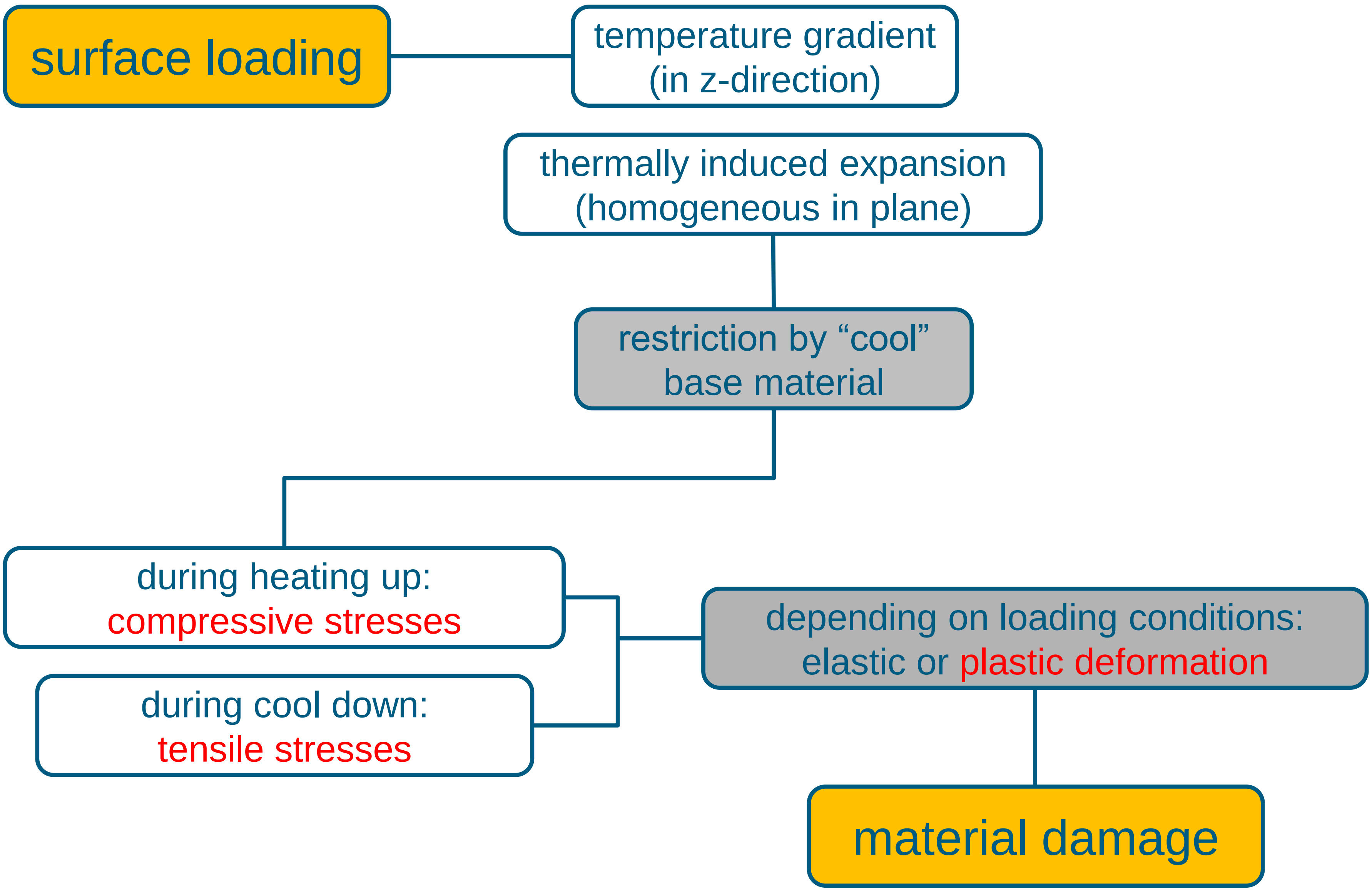
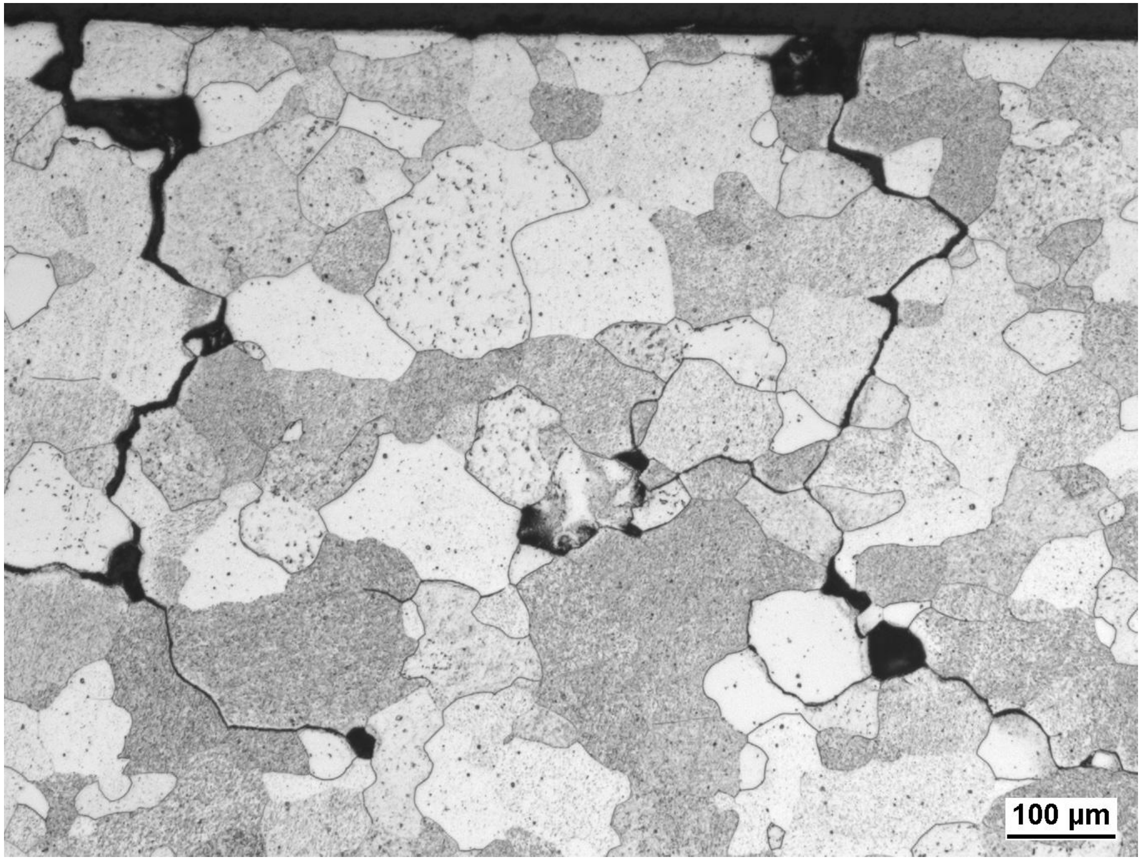
Introduction – thermal shock response



Introduction – thermal shock response

Main problem of tungsten

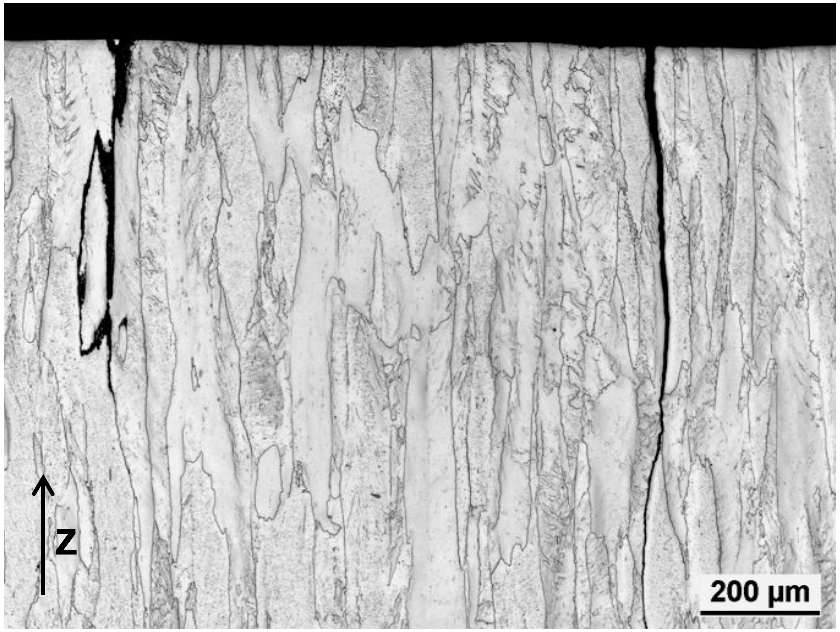
BRITTLENESS (of grain boundaries)



Introduction – thermal shock response

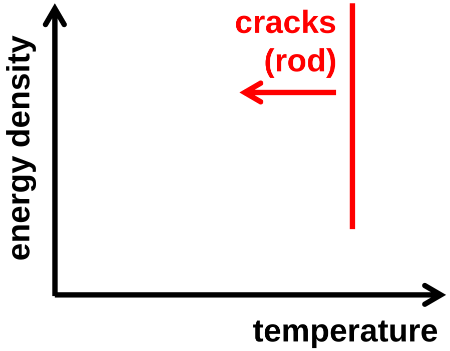
Industrially available grades - ANISOTROPY

ROD



- good mechanical properties in z-direction
- weak mechanical properties in the surface plane

⇒ brittle crack formation up to higher temperatures

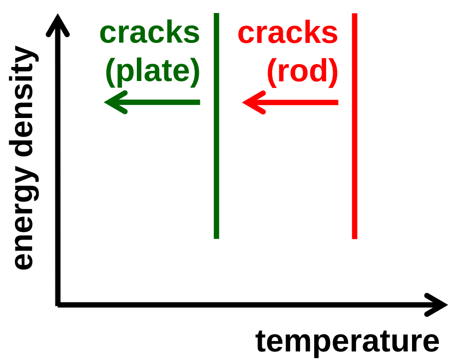


Introduction – thermal shock response

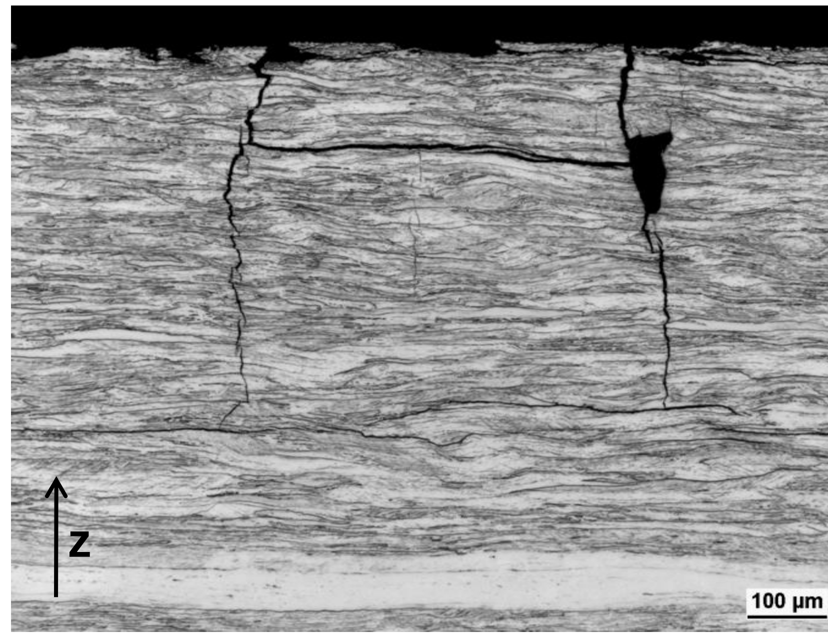
Industrially available grades - ANISOTROPY

- weak mechanical properties in z-direction
- good mechanical properties in the surface plane

⇒ brittle crack formation limited to lower temperatures **BUT** crack formation parallel to the surface

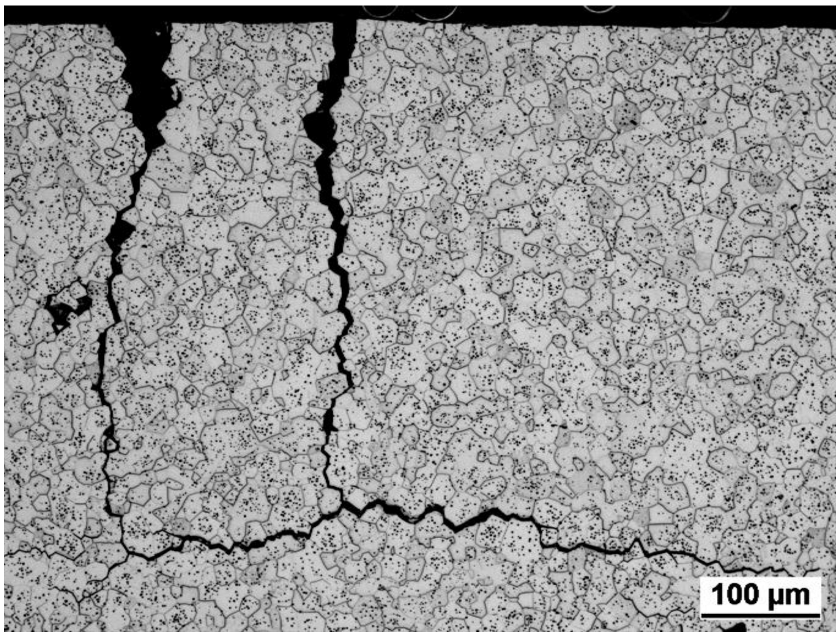


PLATE



Introduction – thermal shock response

ISOTROPIC material, e.g. PIM- W



J. Opschoor et al., Poster P29, PFMC-12, Jülich

- good mechanical properties in all directions

⇒ brittle crack formation limited to lower temperatures **BUT** crack formation parallel to the surface

crack formation parallel to the surface determined by

- temperature gradient (pulse duration, power density)
- resulting thermal stresses

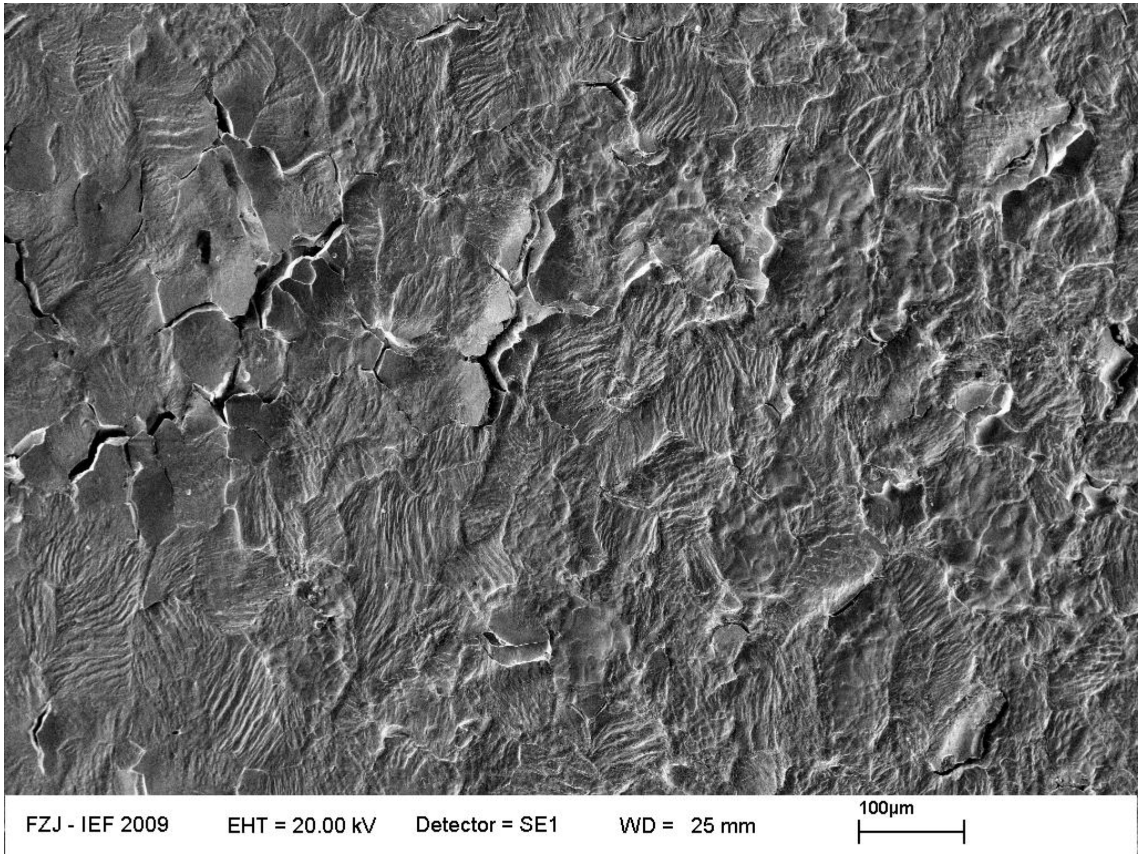
recrystallization / grain growth ⇒ isotropy

BUT: weakening of grain boundaries & reduction of mechanical strength

Introduction – response to thermal shock

Additional problem of tungsten

THERMAL FATIGUE



Introduction – response to thermal shock

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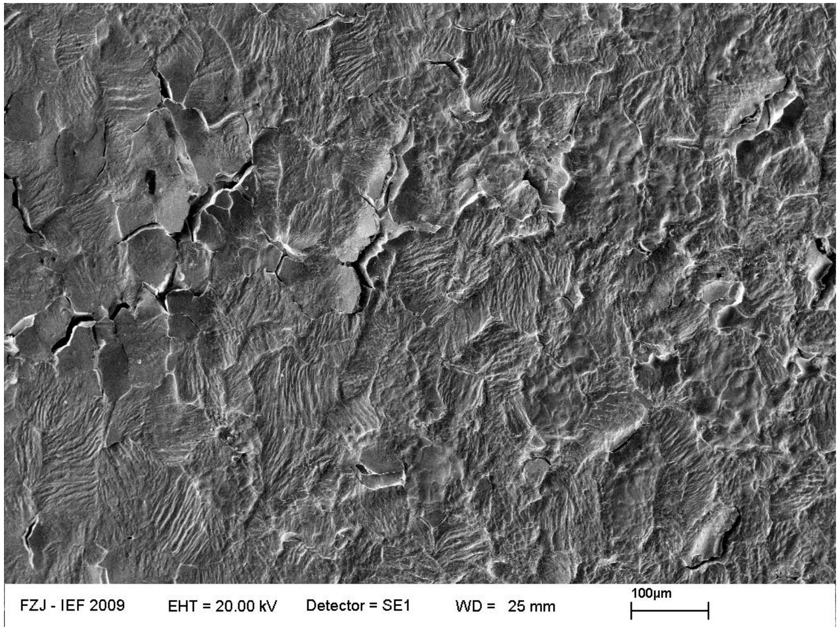
Additional problem of tungsten

THERMAL FATIGUE



depending on

- strength and ductility
- base temperature
- grain size

⇒ plastic deformation leads (sooner or later) to crack formation

(see poster P69A, Th. Loewenhoff et al.)

Conclusion

A material with good thermal shock resistance needs

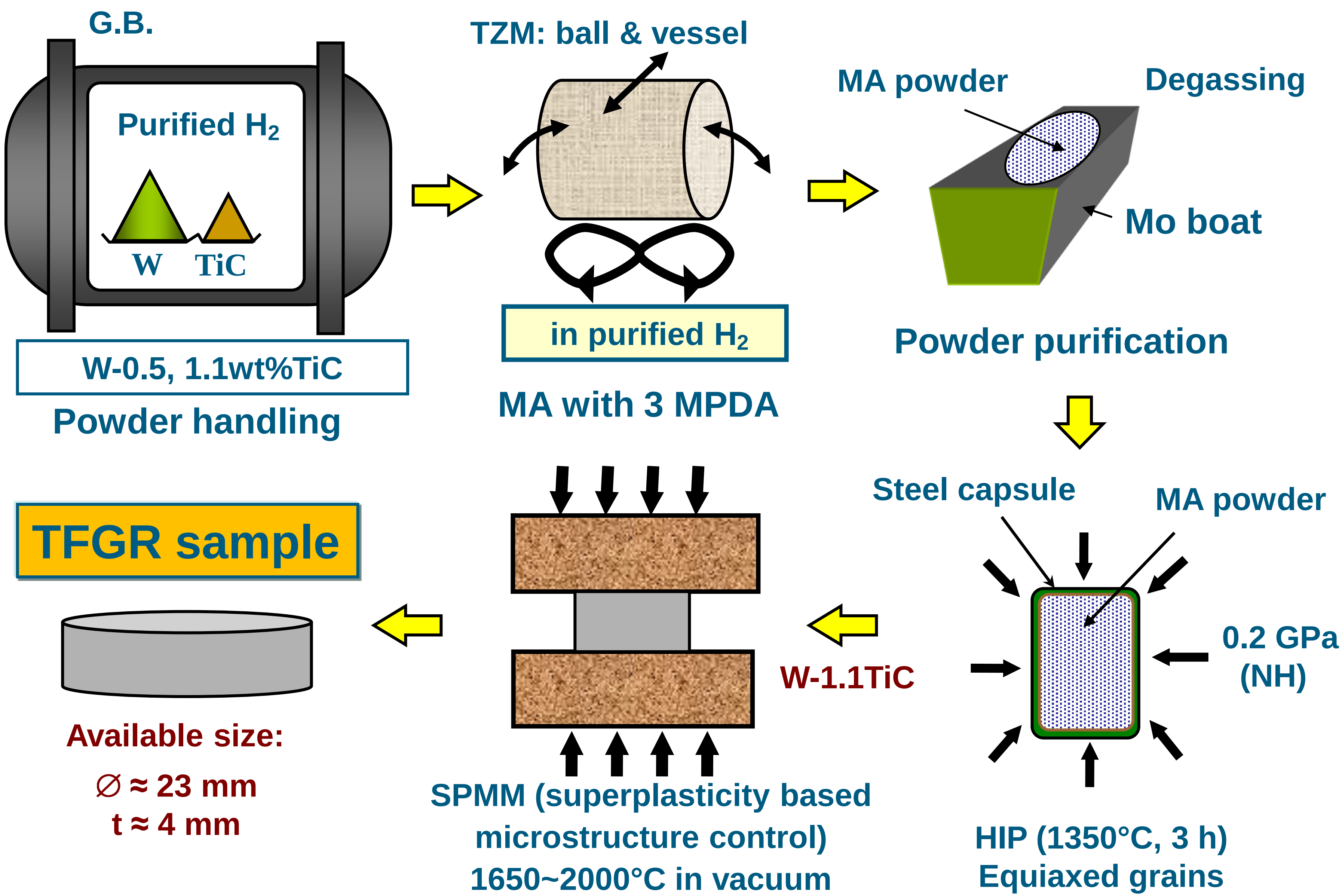
- high strength in all directions
  $\Rightarrow$ **isotropy**
- high strength of grain boundaries
  $\Rightarrow$ **alloying, particle reinforcement**
- high recrystallization resistance
  $\Rightarrow$ **alloying, particle reinforcement, low degree of deformation**
- high thermal fatigue resistance
  $\Rightarrow$ **fine grained materials**

$\Rightarrow$ W-TiC

<u>Other needs</u>

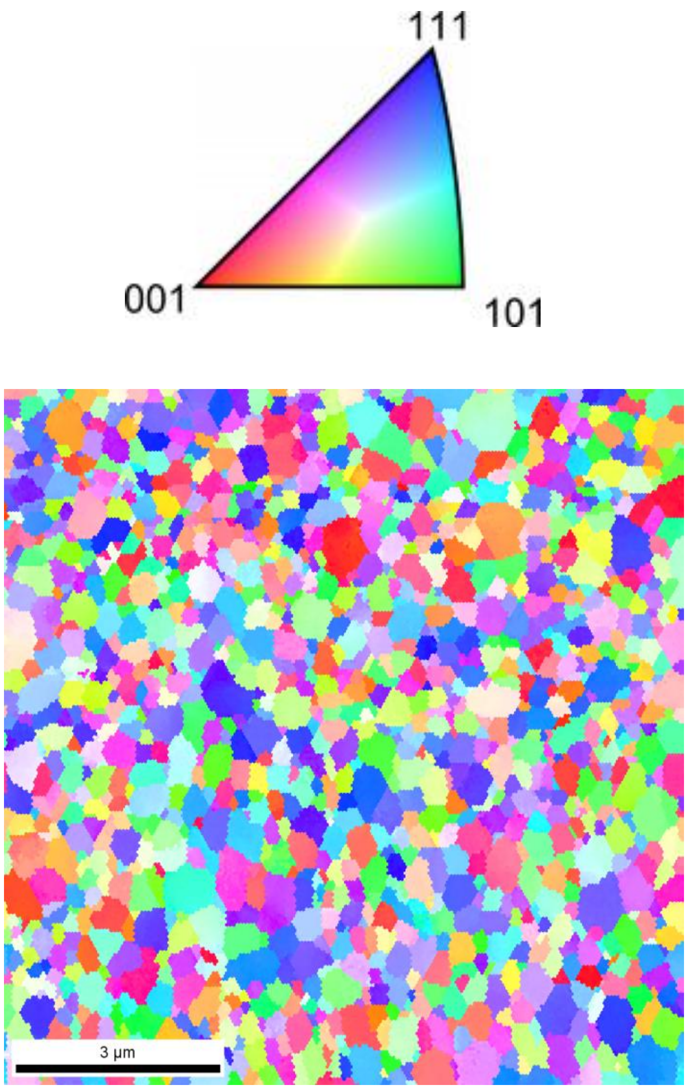
- resistance to H, He and neutrons

Processing

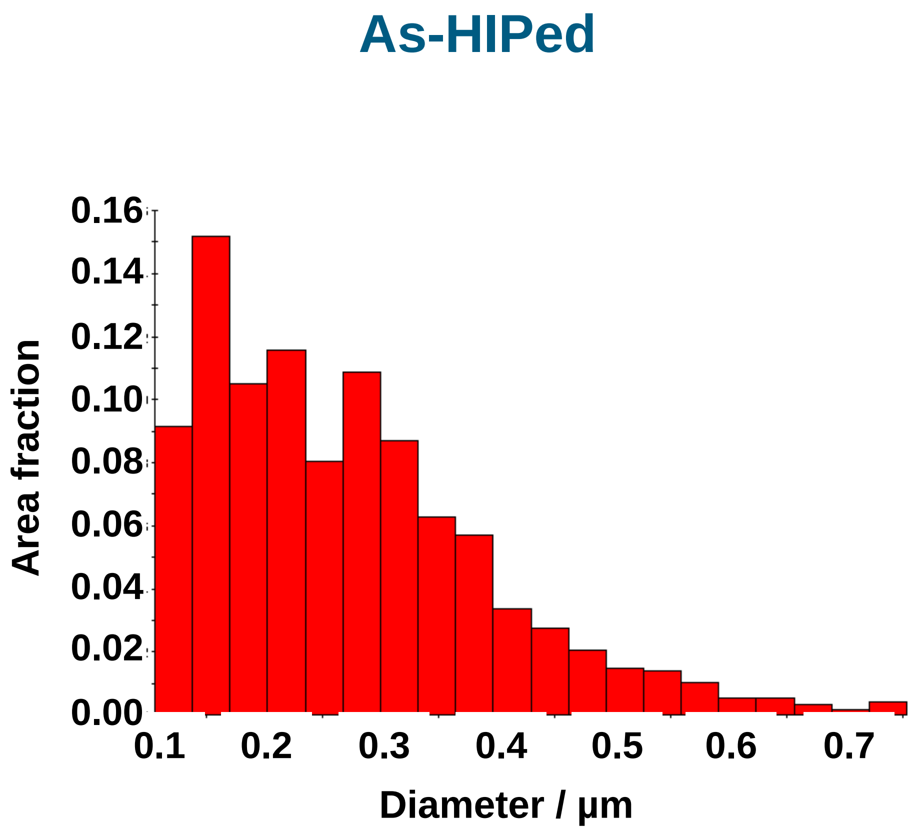


TFGR = Toughness Enhanced Fine Grained Material in the Recrystallized State

Grain distribution in UFG W-0.5TiC

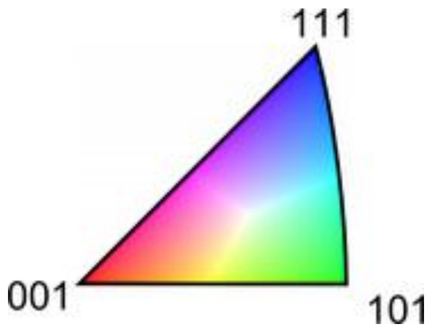


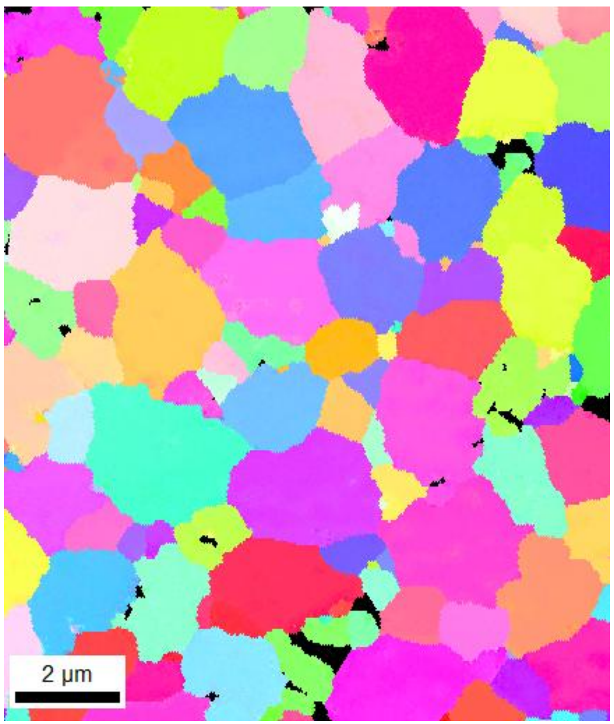
Equiaxed grains



By S. Tsurekawa et al.

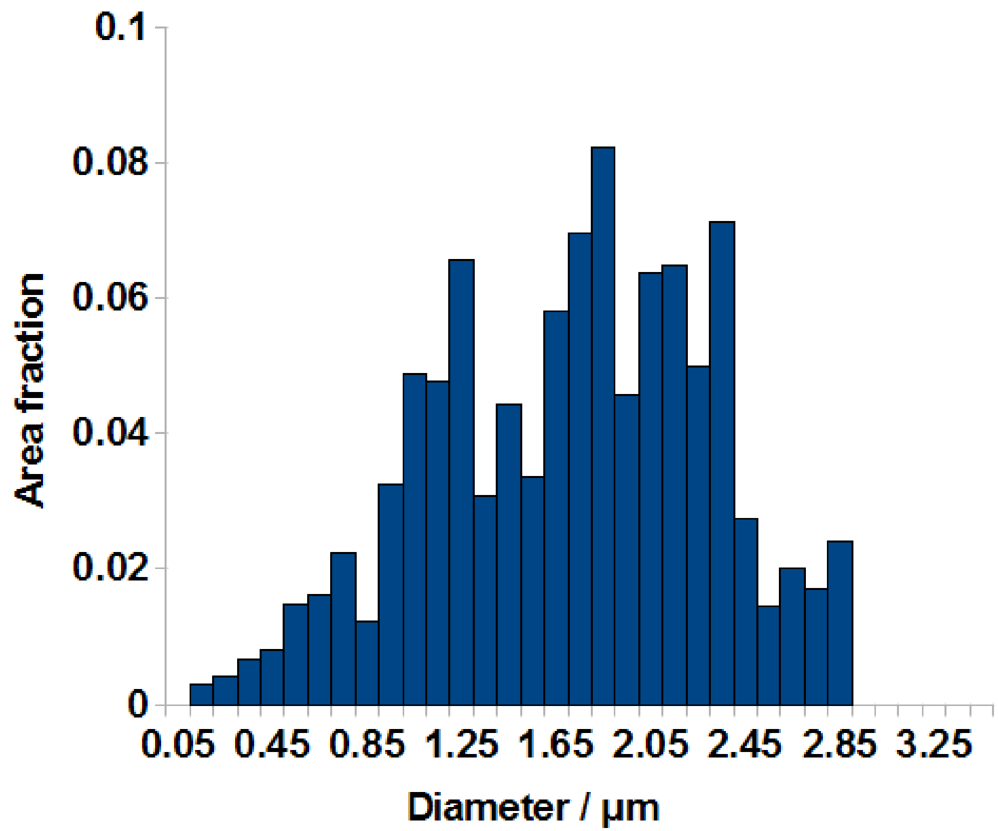
Grain distribution in TFGR W-1.1TiC





Equiaxed grains

SPMM: 1600 C x 3 h



By S. Tsurekawa et al.

Effect of SPMM temp. on microstructure

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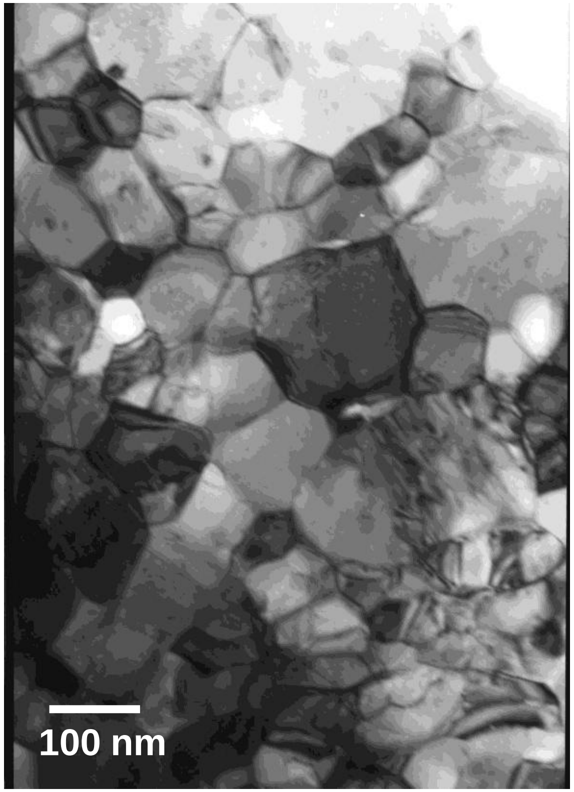
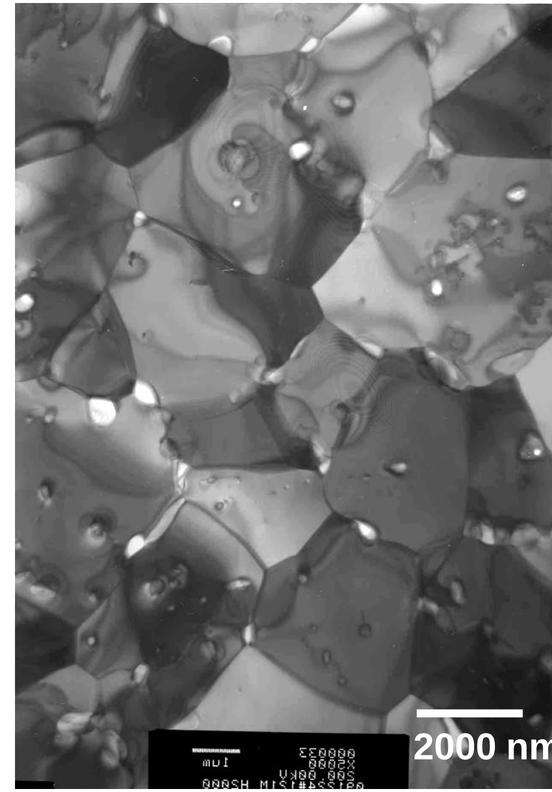
UFG W-1.1TiC

TFGR W-1.1TiC





As-HIPed: 1350 C x 3h

Grain size: 90 nm

SPMM: 1650 C x 3h

Grain size: 1480 nm

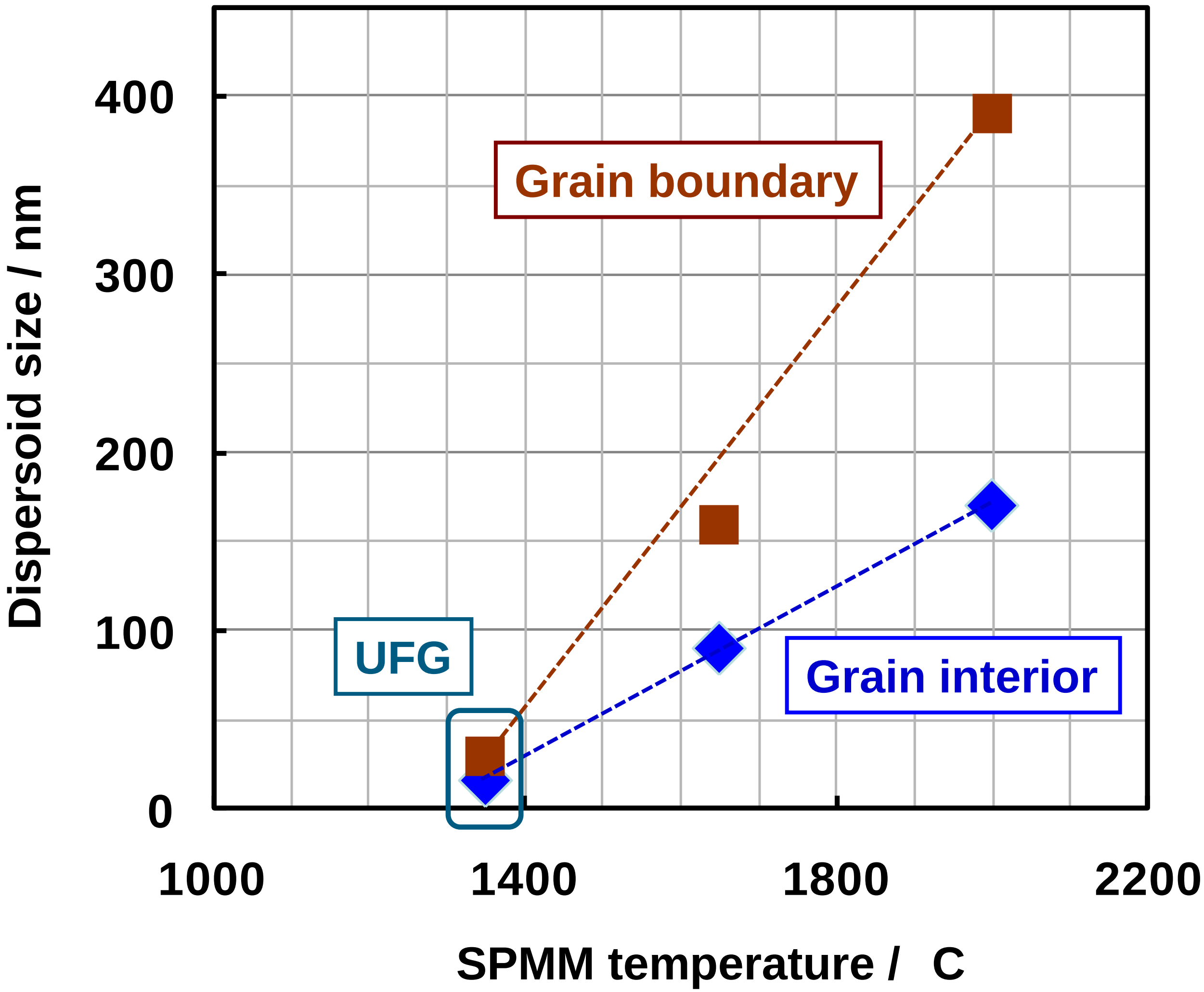
SPMM: 1650-2000 C x 3h

Grain size: 2900 nm

By T. Sakamoto et al.

Effect of SPMM temp. on TiC dispersoid size

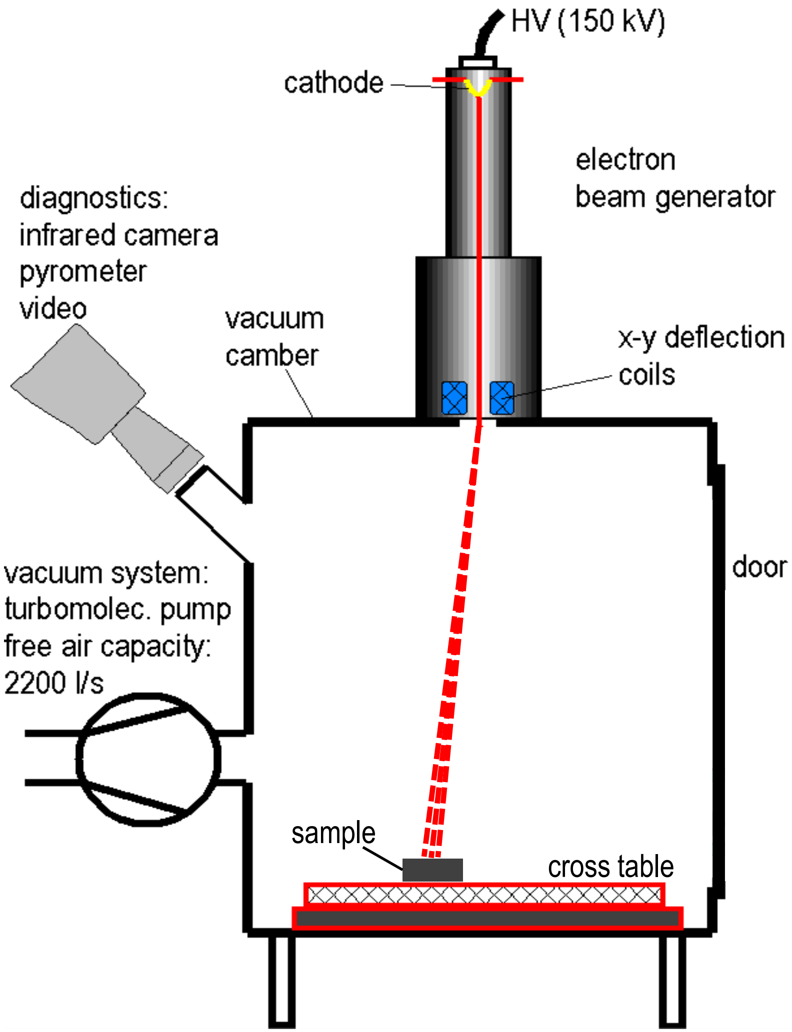
UFG & TFGR W-1.1TiC



By T. Sakamoto et al.

Facility, materials and loading conditions

JUDITH 1



Materials

UFG

- W-0.5TiC / H_2

TFGR

- W-1.1TiC / H_2, 1650 °C, ~800 ppm O
- W-1.1TiC / H_2, 1850 °C, ~800 ppm O
- W-1.1TiC / H_2, 1650 °C, ~200 ppm O

Loading conditions

$A = 16\ mm^2$

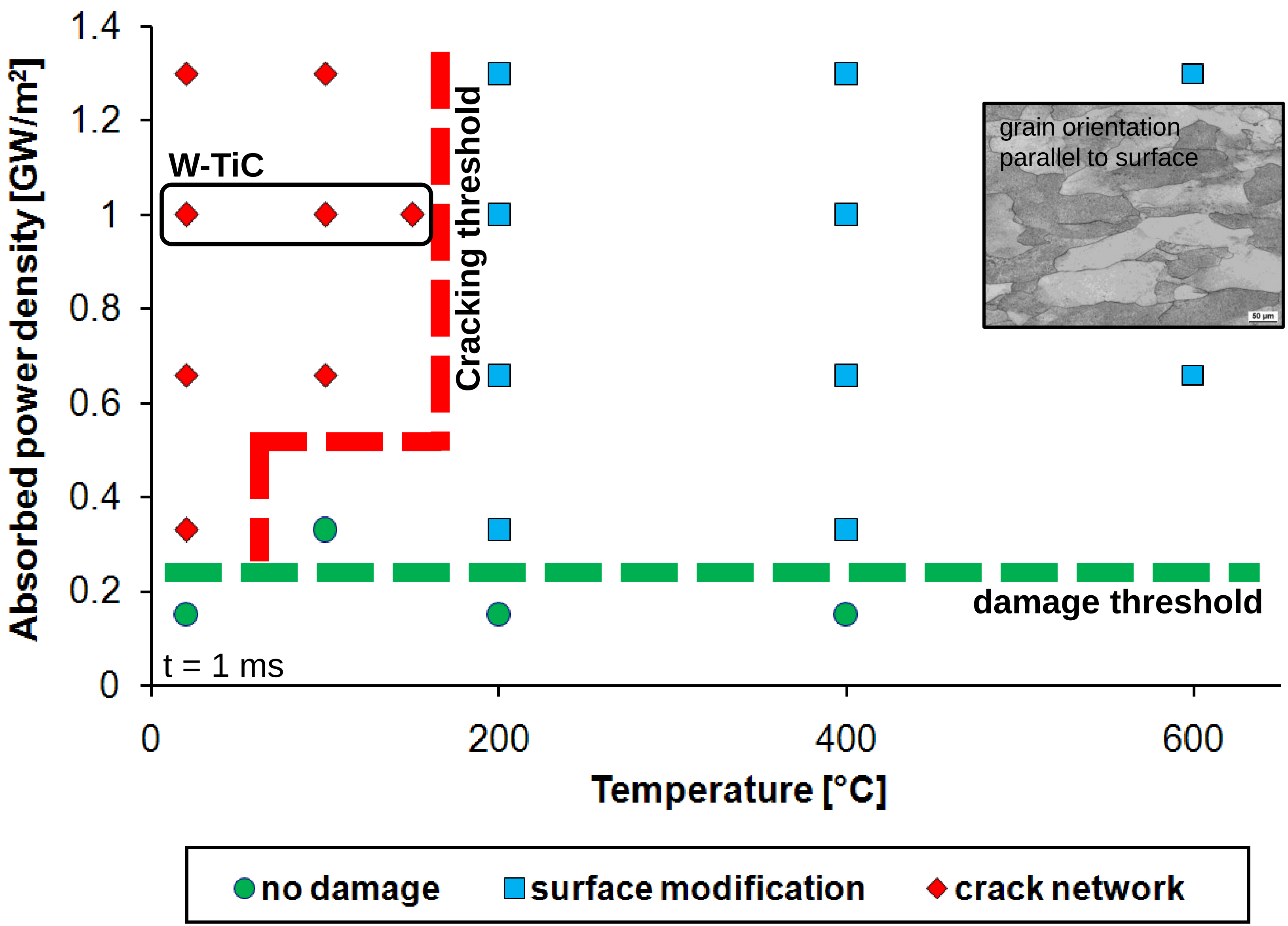
$t = 1\ ms$

$P = 1.1\ GW/m^2$ (pure W: $\Delta T \approx 2000$ °C)

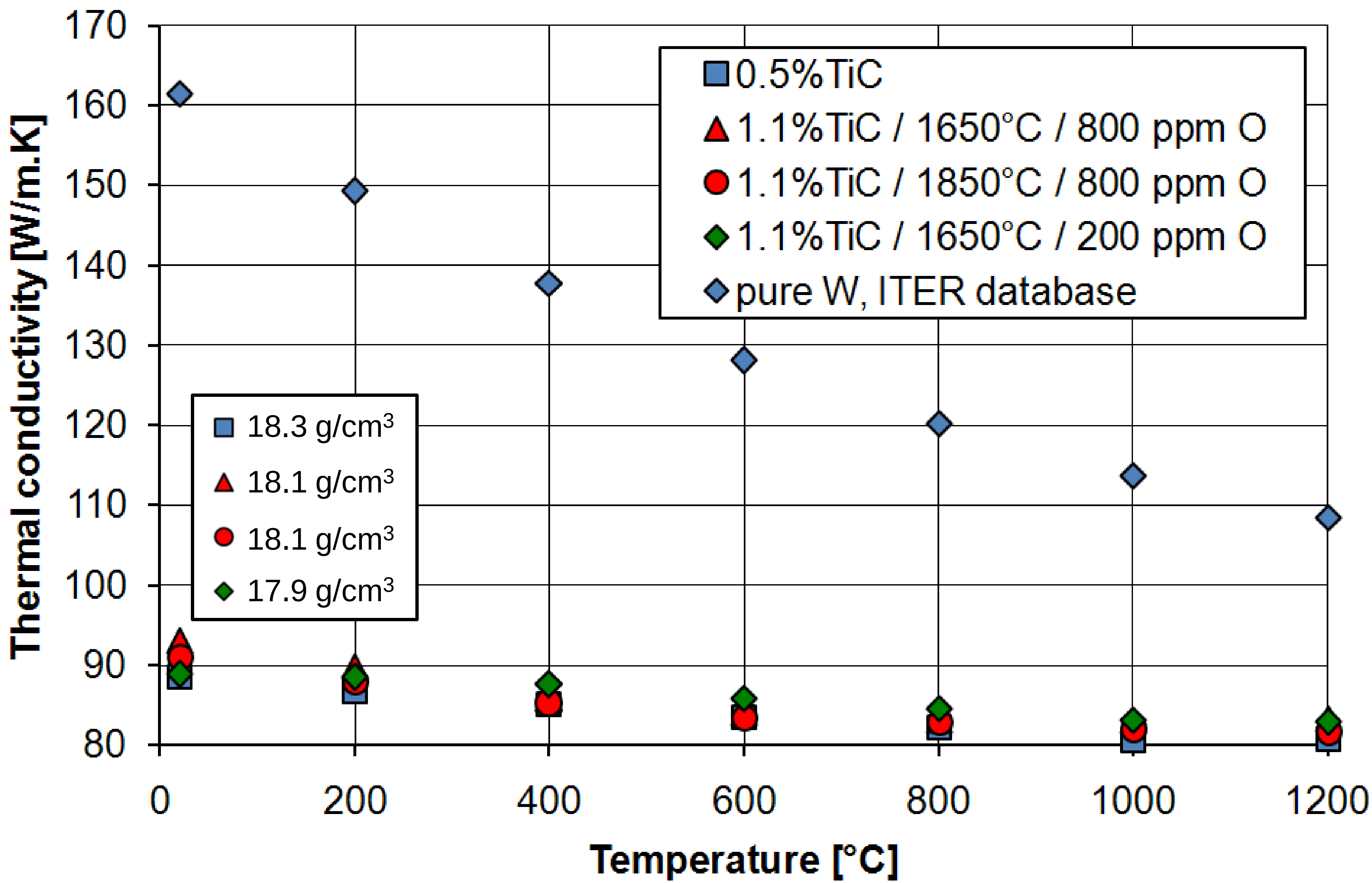
T_{base} = RT, 100 °C, 150 °C

$n = 100$

Thermal shock results: double forged tungsten

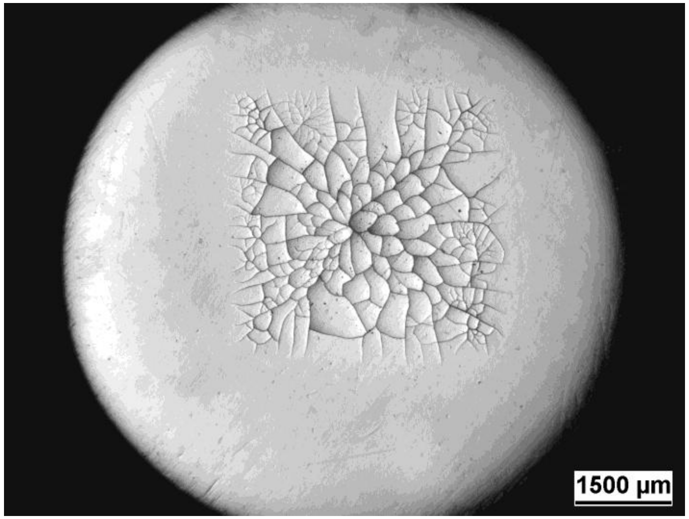


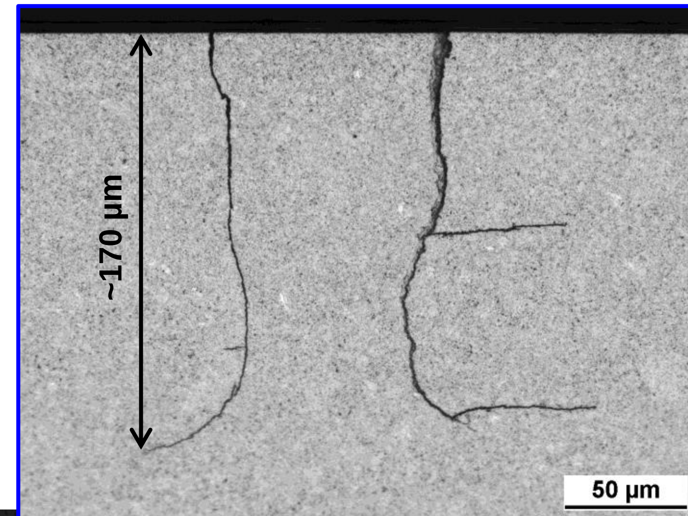
Thermal conductivity

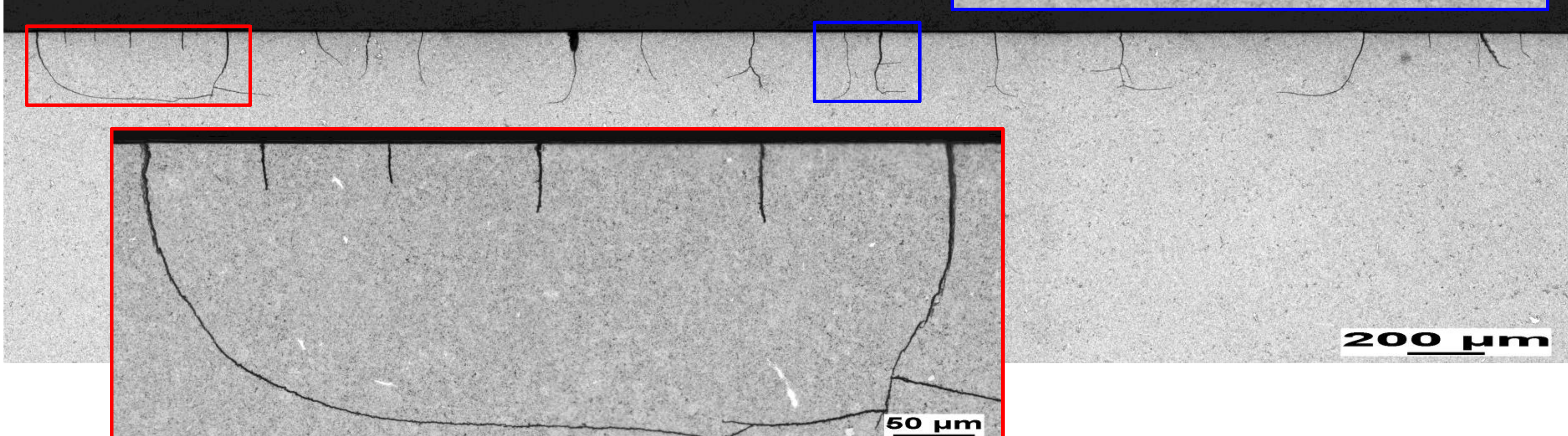


Results at T_{base} = 100 °C

- **W-0.5TiC**







Results at T_{base} = 100 °C

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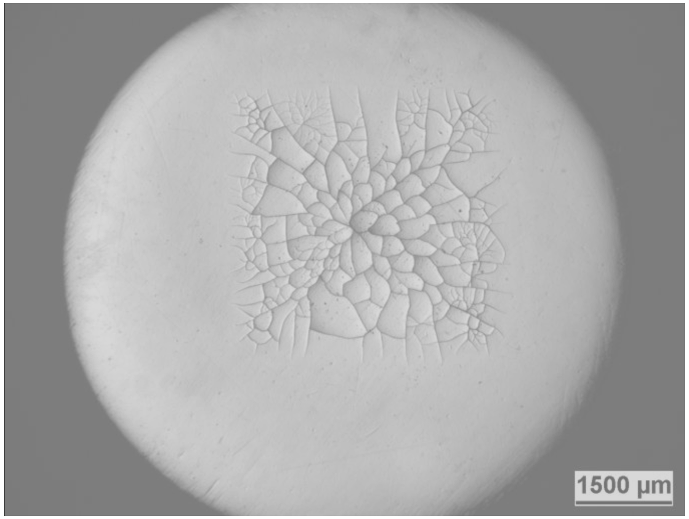
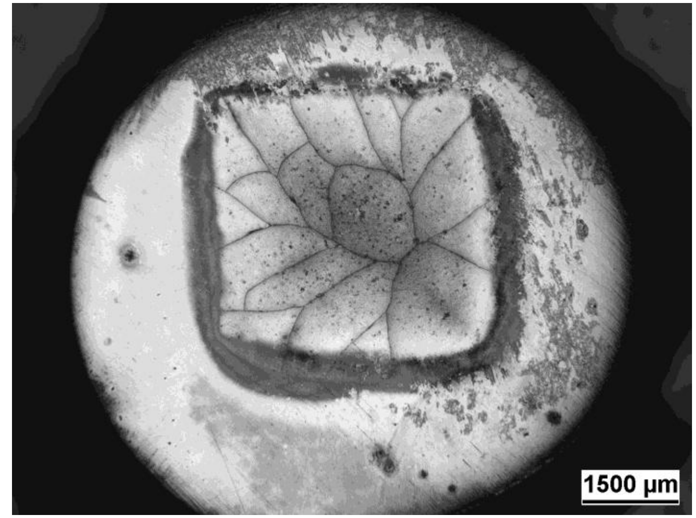
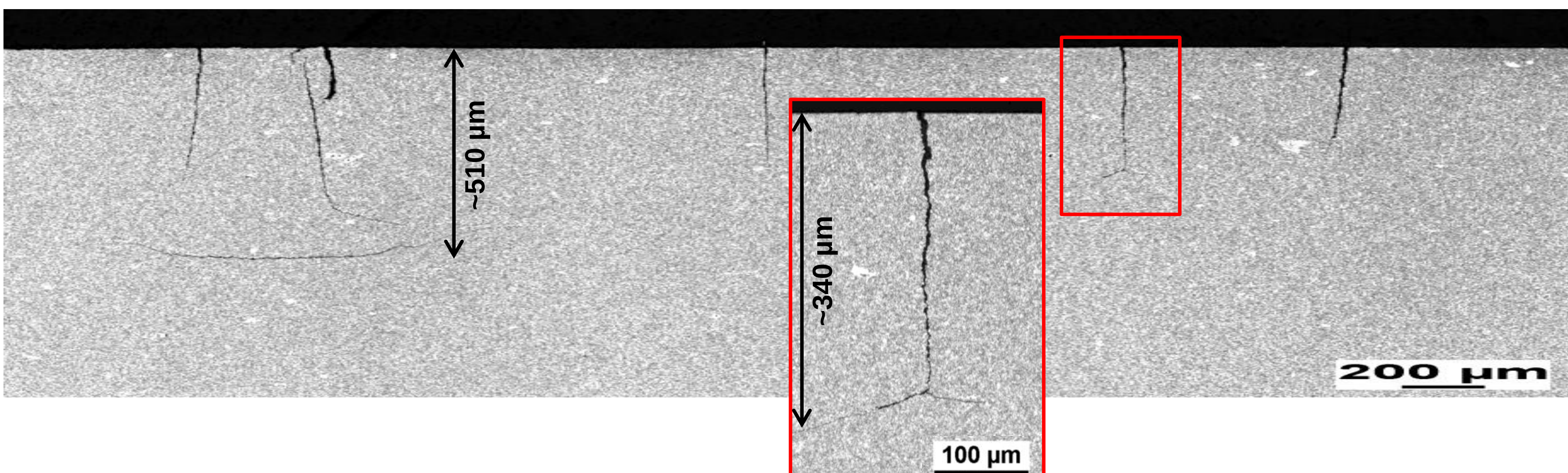


- W-1.1TiC / 1850°C / 800 ppm O





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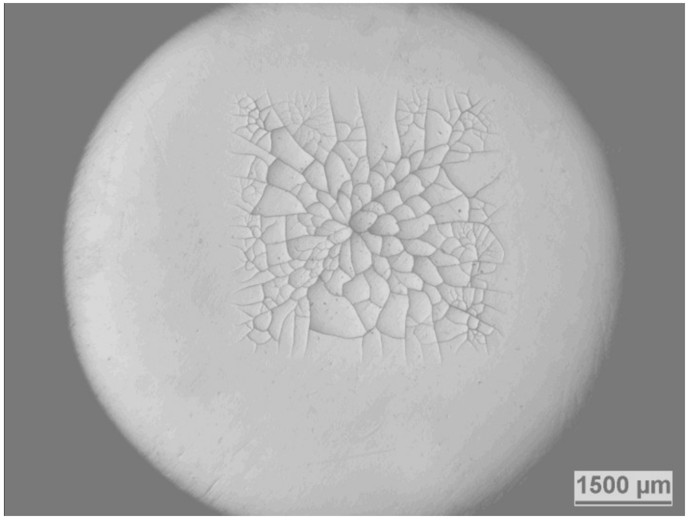

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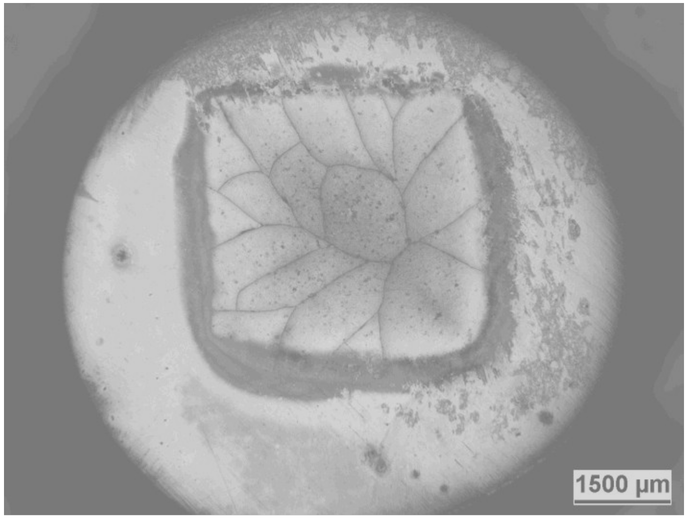
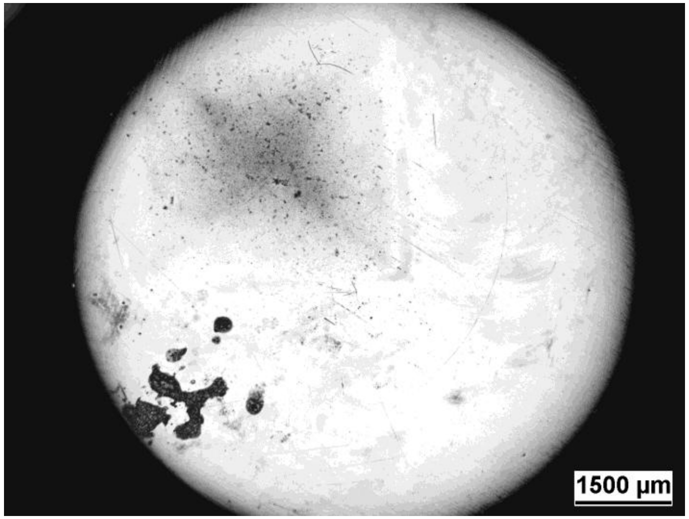
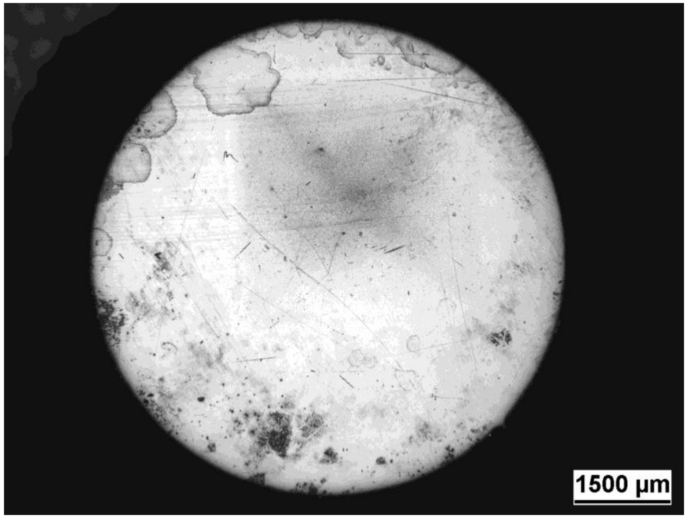


- W-1.1TiC / 1650°C / 800 ppm O

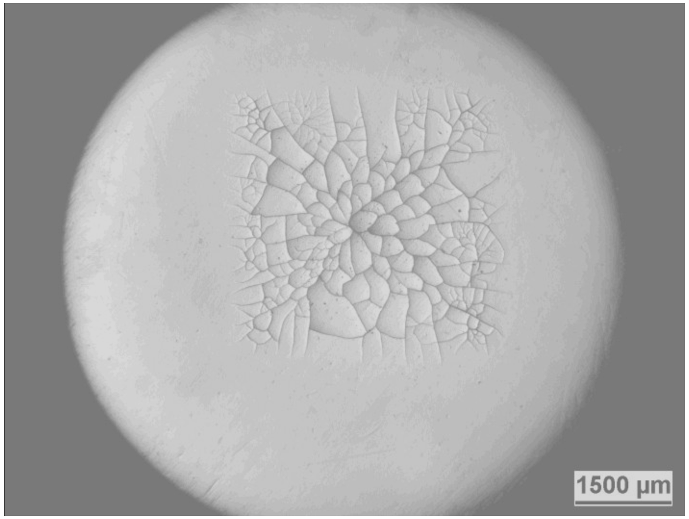


- W-1.1TiC / 1650°C / 200 ppm O



Results at T_{base} = 100 °C

- W-0.5TiC



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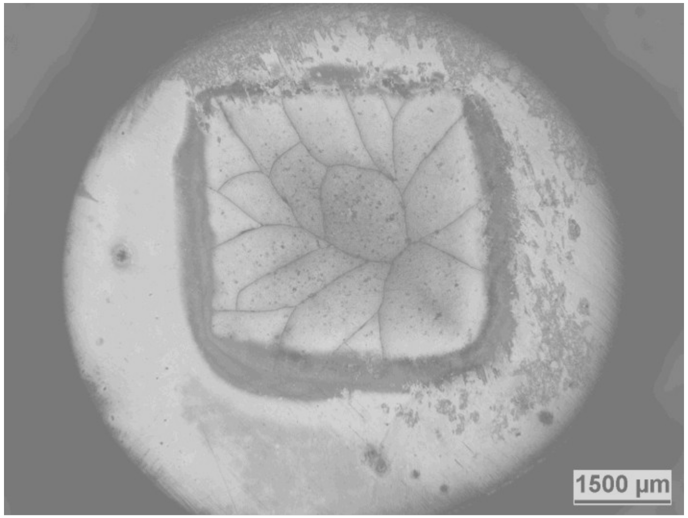

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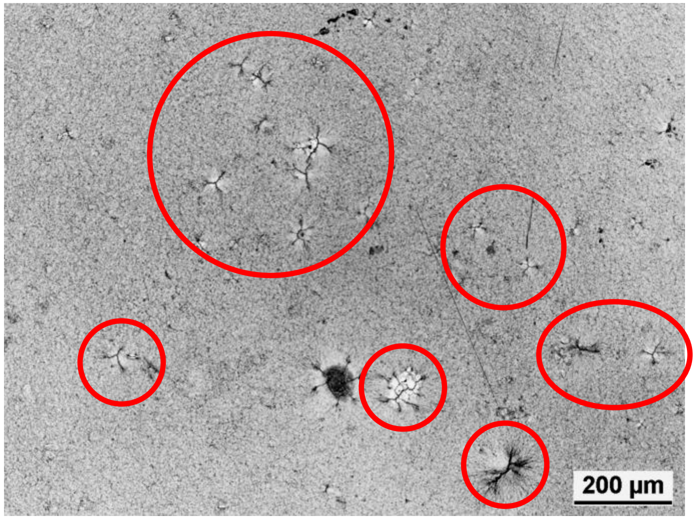

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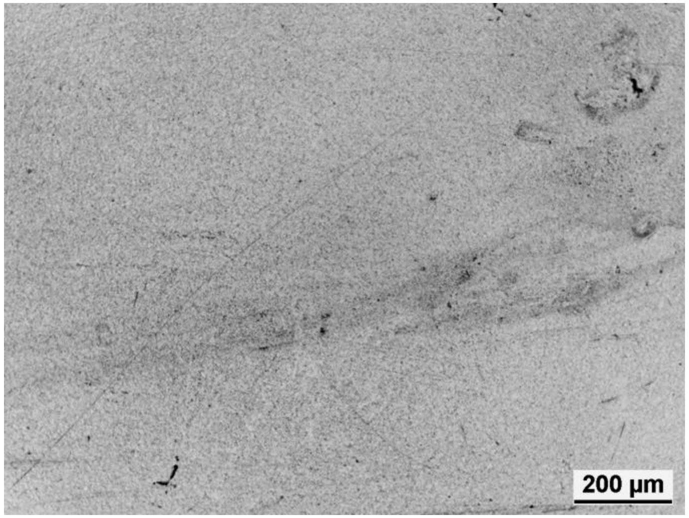

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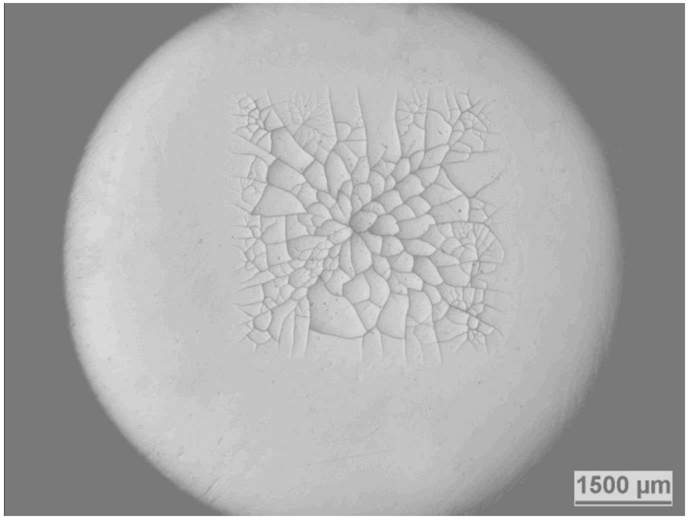

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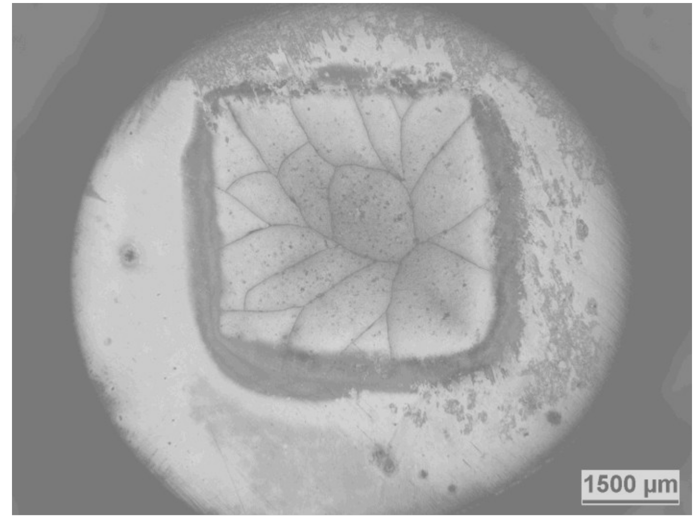

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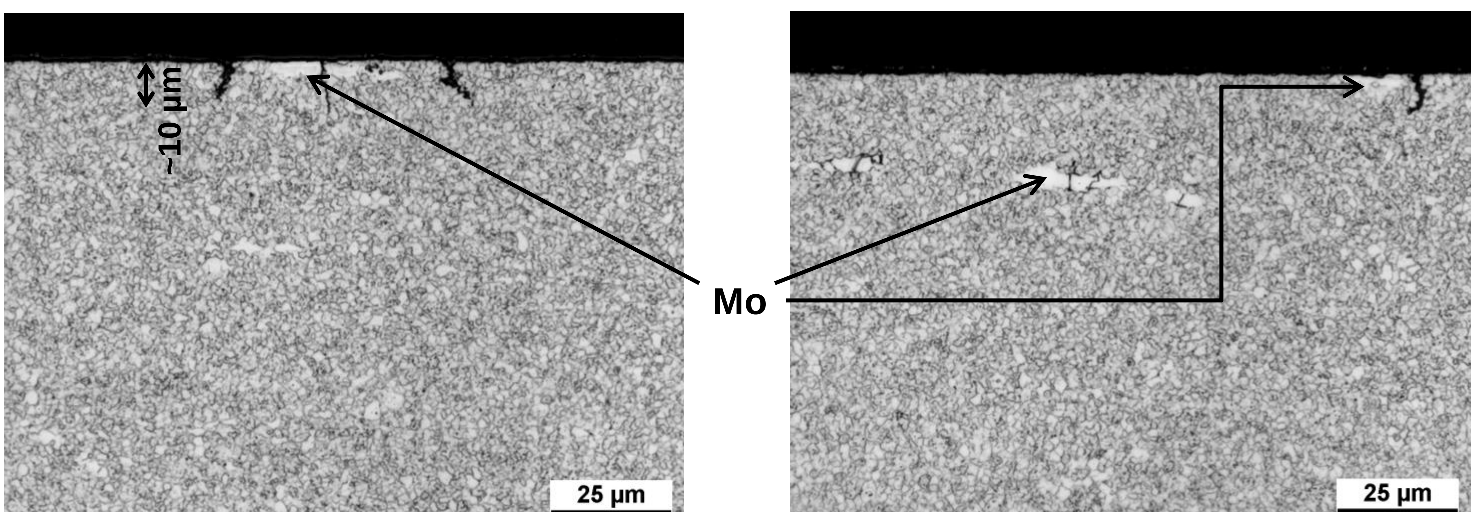
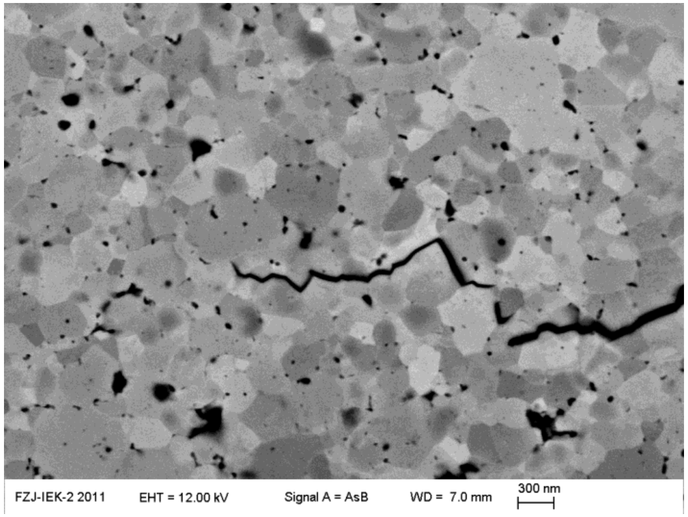


Microstructure & TiC-distribution

- **W-0.5TiC**



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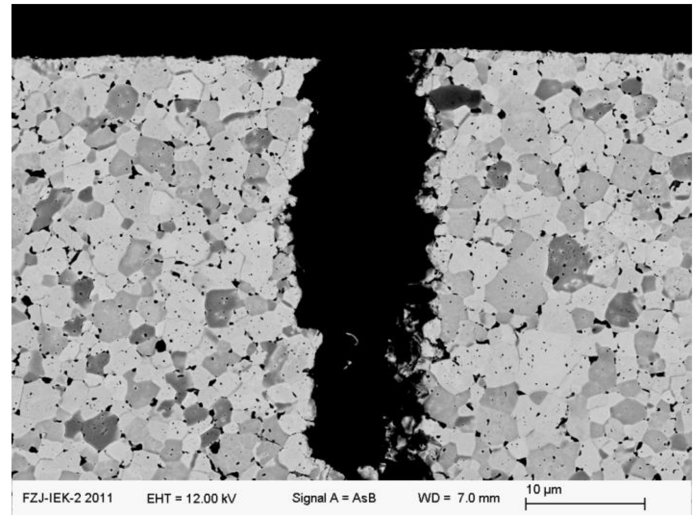
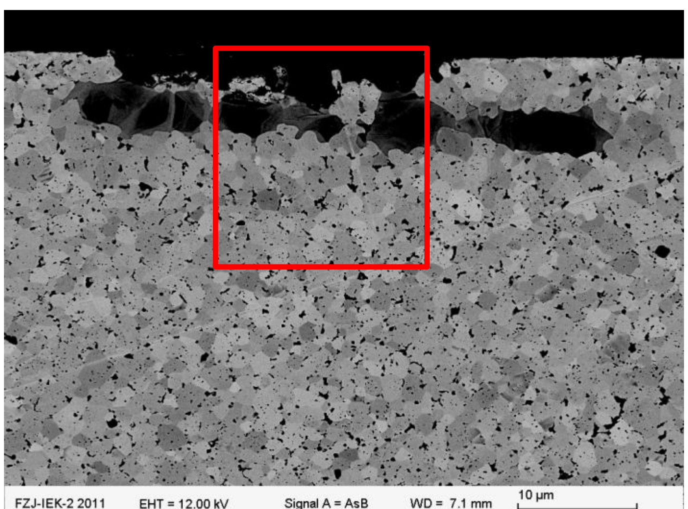
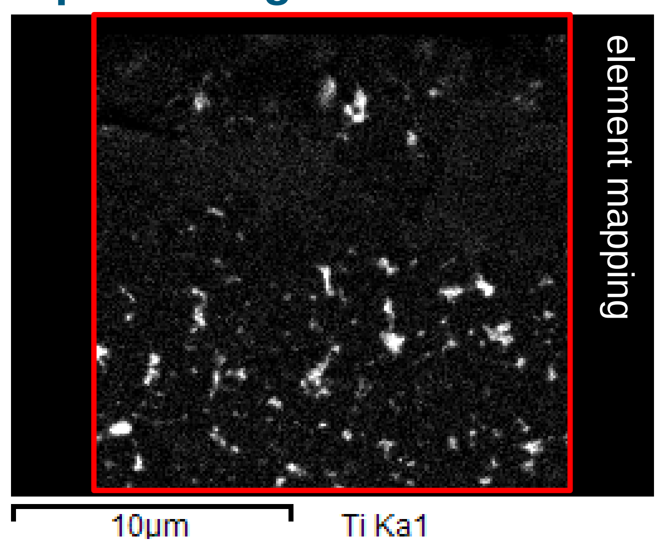


- **W-1.1TiC / 1650°C / 800 ppm O ⇒ optimized grain size / TiC distribution**





Results: W-1.1TiC / H_2, 1650 °C, ~200 ppm O

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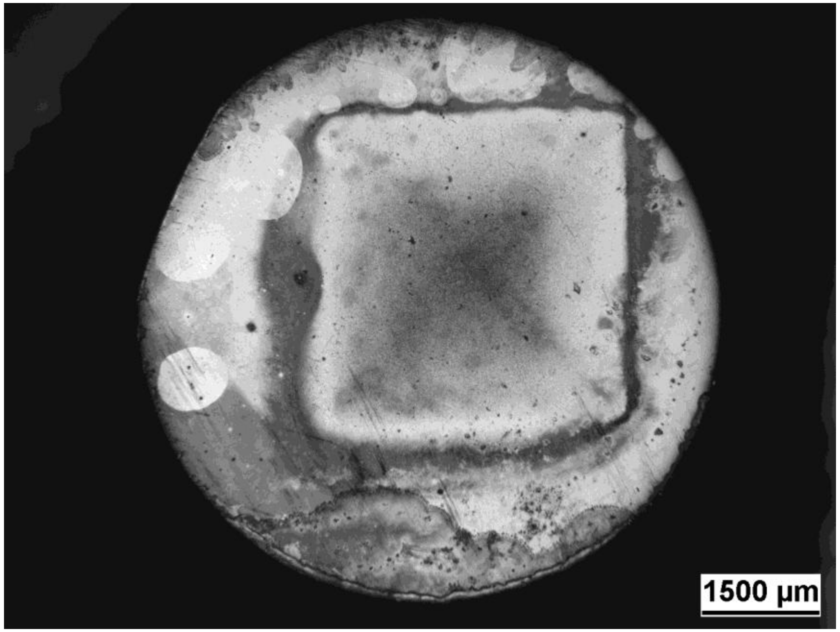
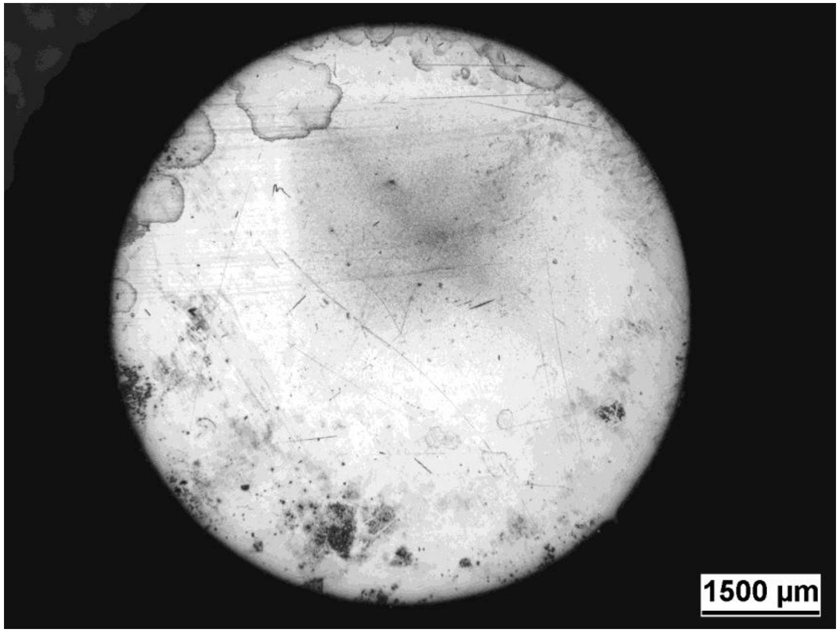
- T_{base} = RT



- T_{base} = 100 °C



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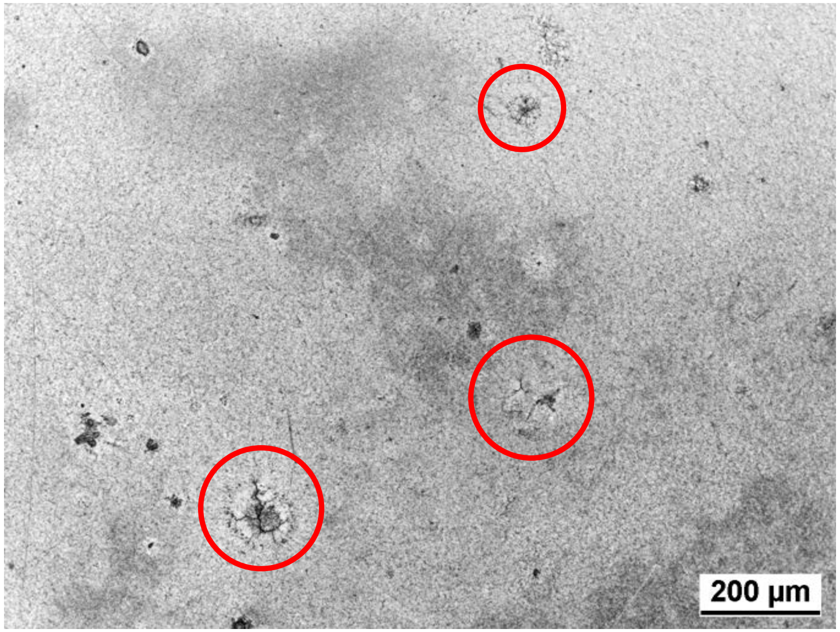

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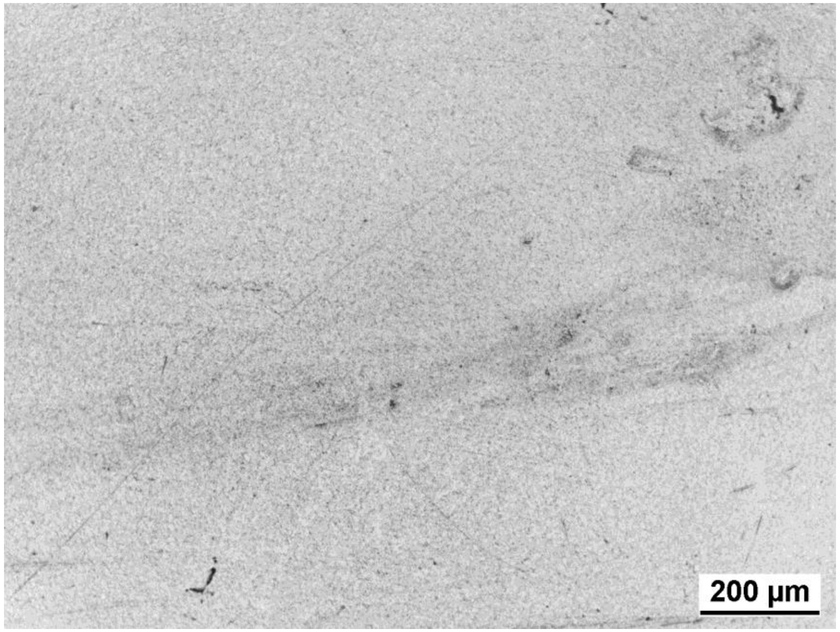

- via laser profilometry no detectable surface roughening after 100 pulses

Conclusion

Improvement of

- **cracking threshold** (T_{base} ↓ **to RT**)

of **W-TiC** due to

- **TiC-content: 0.5 % ⇒ 1.1 % (UFG ⇒ TFGR)**
- **manufacturing temperature: 1850°C ⇒ 1650°C**
- **oxygen content: 800 ppm ⇒ 200 ppm**

Future work

- reduction of impurities (large Mo-grains) acting as crack initiation points
- investigation of thermal fatigue resistance as function of temperature
- H*, He*,**, neutrons** in combination with thermal shock / thermal fatigue
- industrial upscale???

** H. Kurishita et al., JNM 398, 2010, 87*
*** H. Kurishita et al., JNM 377, 2008, 34*