

Ductilisation of W: Synthesis, analyses and characterization of W-laminates made of W-foils

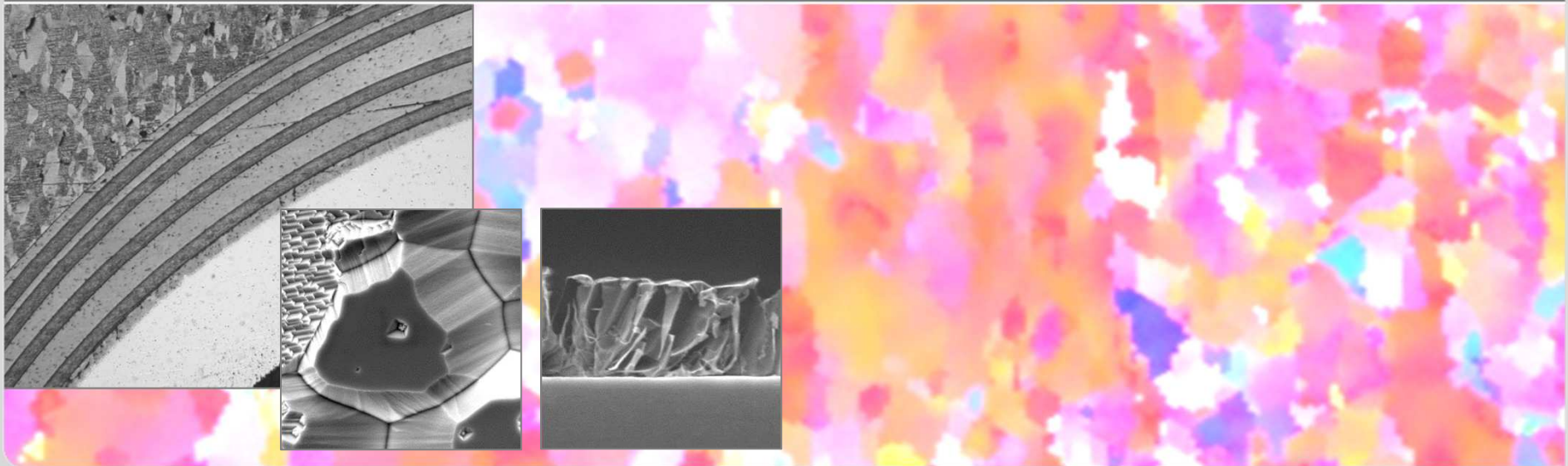
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¹ Karlsruhe Institute of Technology, Institute for Applied Materials, Germany

² PLANSEE SE, Reutte, Austria

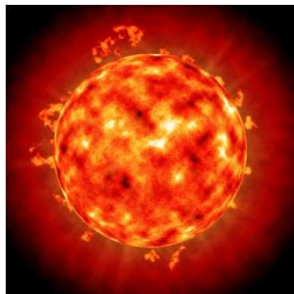
18th PLANSEE seminar, 3 – 7 June 2013, Reutte

INSTITUTE FOR APPLIED MATERIALS, APPLIED MATERIALS PHYSICS

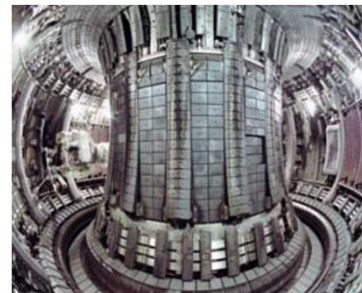
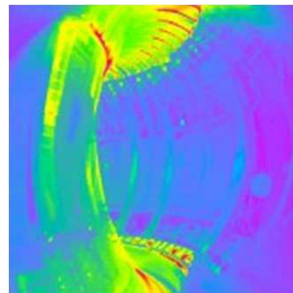


What is the problem?

- Divertor applications ask for a high temperature (1000°C) **structural** material
- W is the metal with the highest melting point of all metals ($T_S = 3422^\circ\text{C}$)
- Disadvantages:
 - Low fracture toughness, K_{IC} [$\text{MPa m}^{1/2}$]
 - High brittle-to-ductile transition temperature (BDTT)



picture: ITER



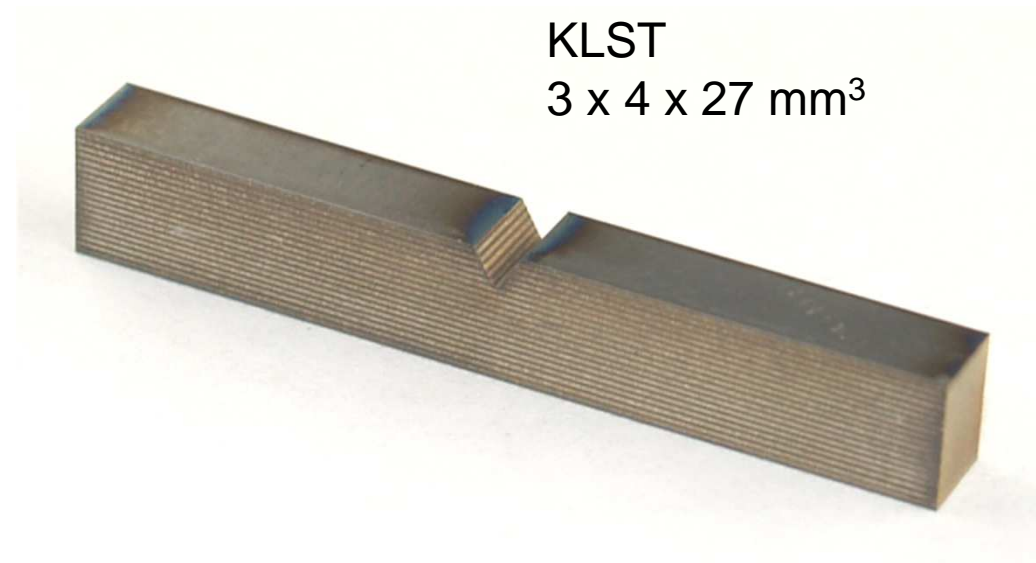
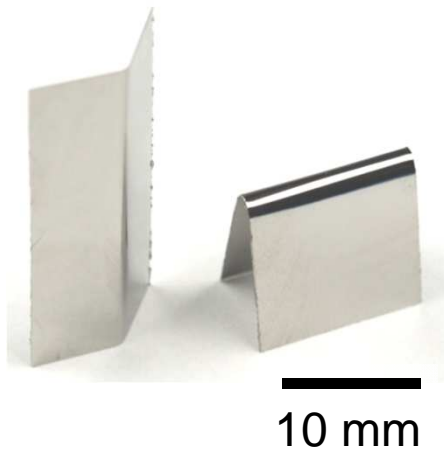
Tokamak fusion reactor



picture: PLANSEE SE

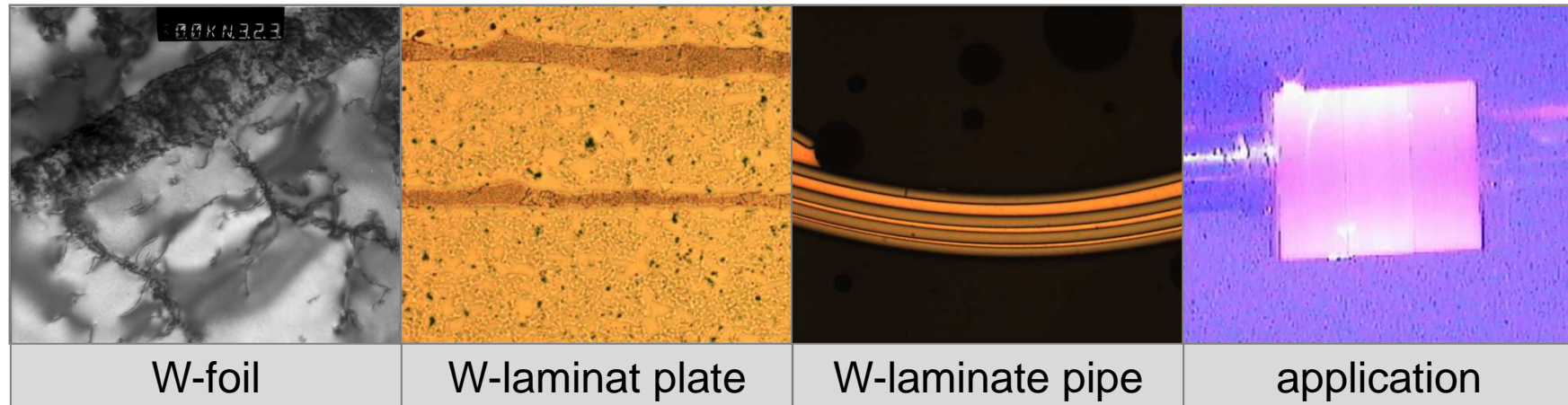
Main question

- Is it possible to expand the ductile properties of a W-foil to the bulk?



Contents

- Analyses of W-foil
 - Electron microscopy, 3PB, tensile tests
- Synthesis of W-laminate plates
 - Charpy impact tests
- Synthesis of W-laminate pipes
 - Charpy, burst test
- Outlook: W-laminates for high heat flux applications



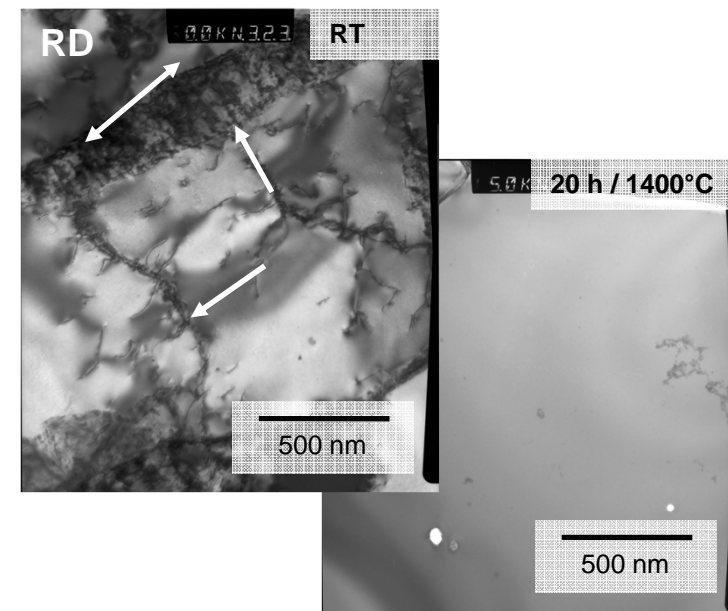
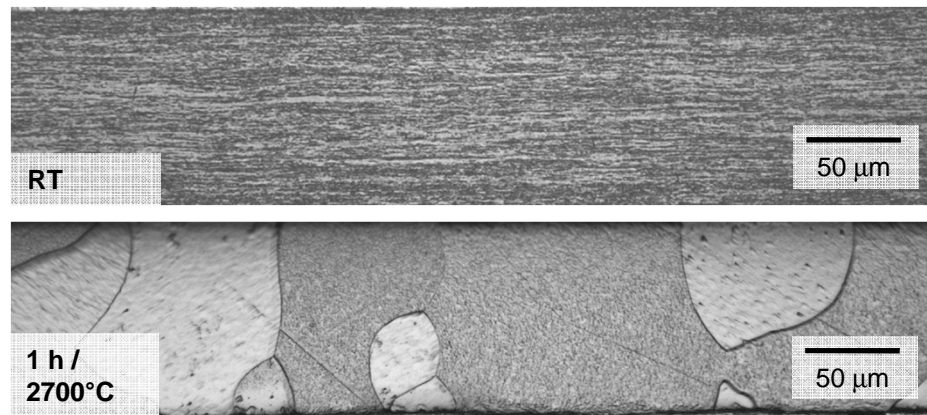
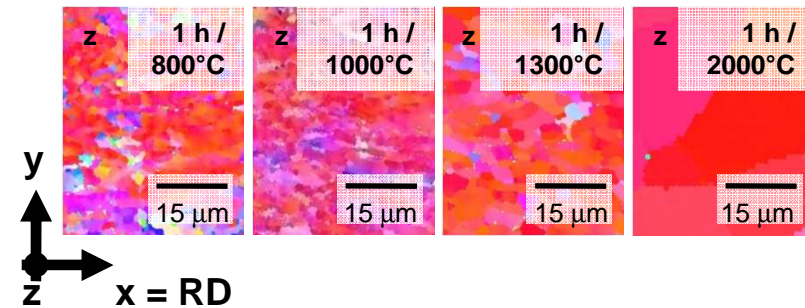
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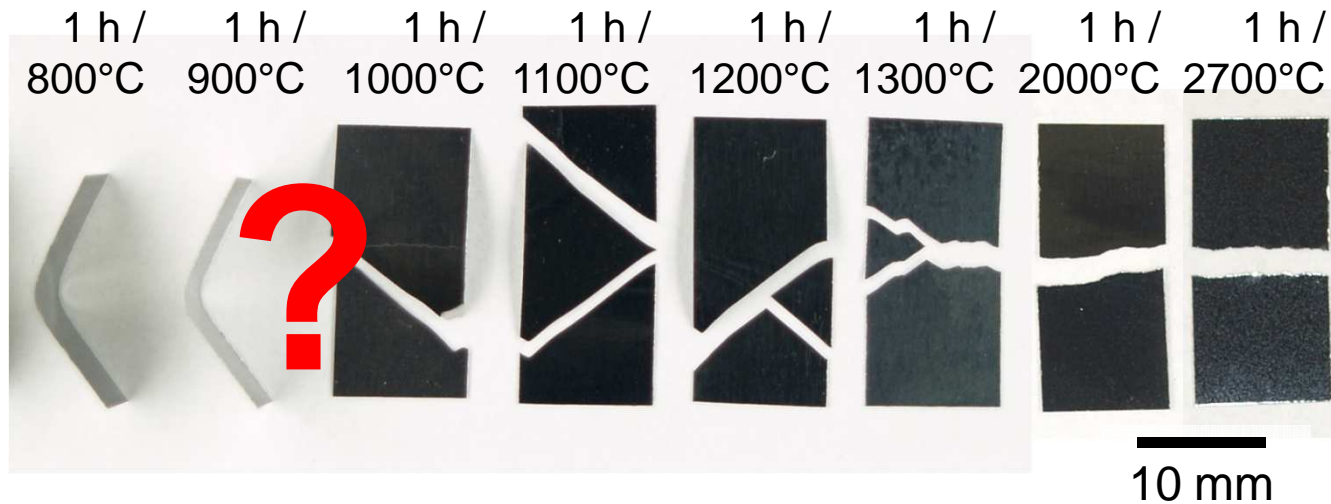
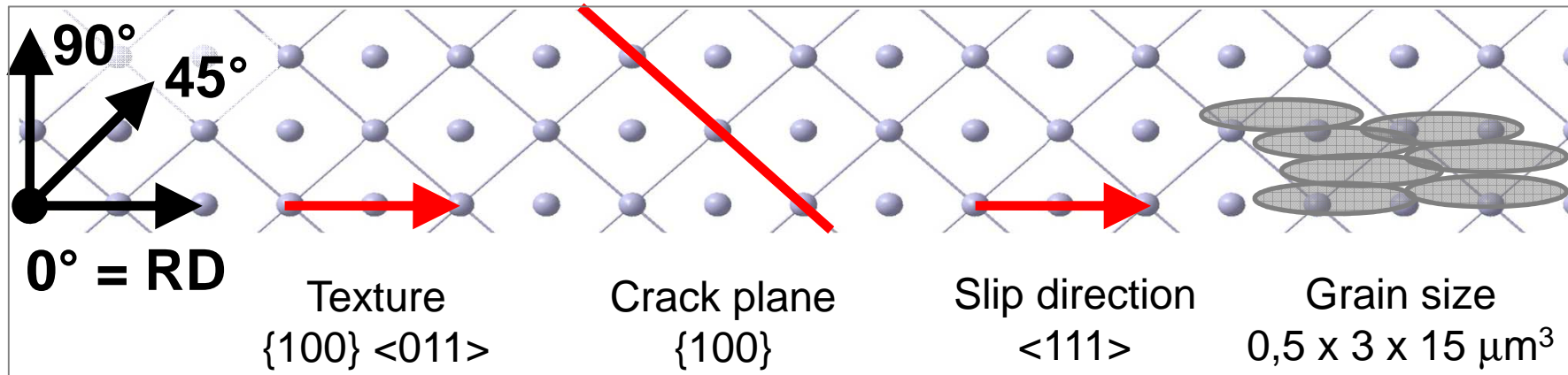
Microstructure of W-foil, 100 μm

- Grain size:
 - As-received: $0.5 \times 3 \times 15 \mu\text{m}^3$
 - 1 h / 2700°C: $100 \times 100 \times 100 \mu\text{m}^3$
- Texture: $\{100\} \langle 011 \rangle$; rotated cube
- Sub grains: nearly free from disl.
- Begin rxx: 1200°C

(pictures: J. Reiser, Y. Xiaou, D.E.J. Armstrong)



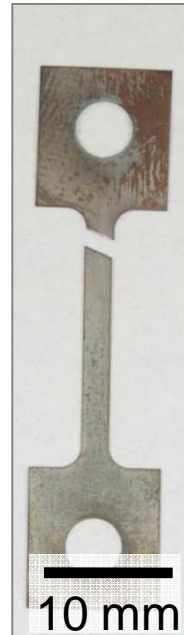
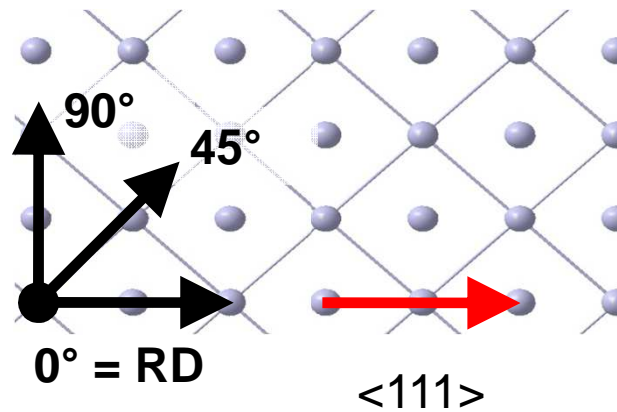
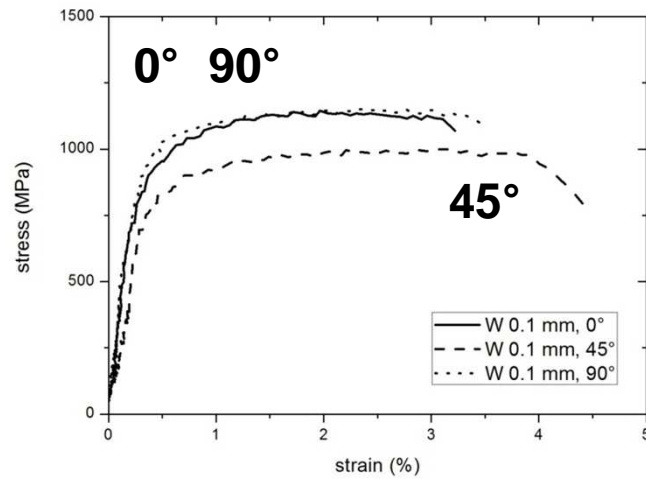
3PB-tests on W-foil, 100 μm



Tensile tests on W-foil, 100 μm

As-received, 600°C

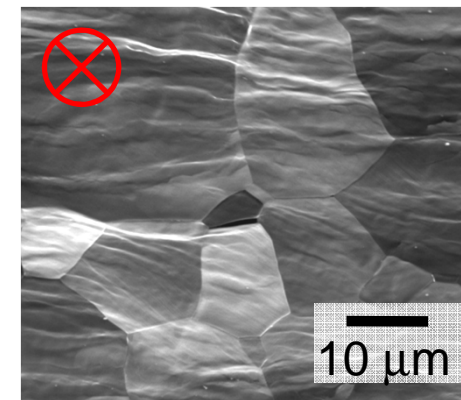
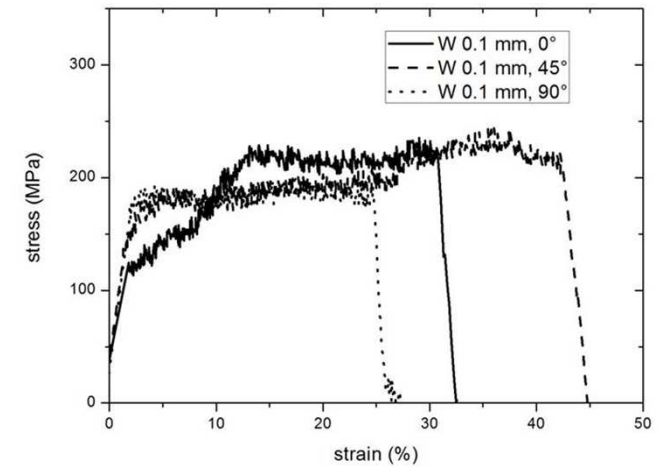
1 h / 2000°C, 600°C



As-received



1 h / 2000°C



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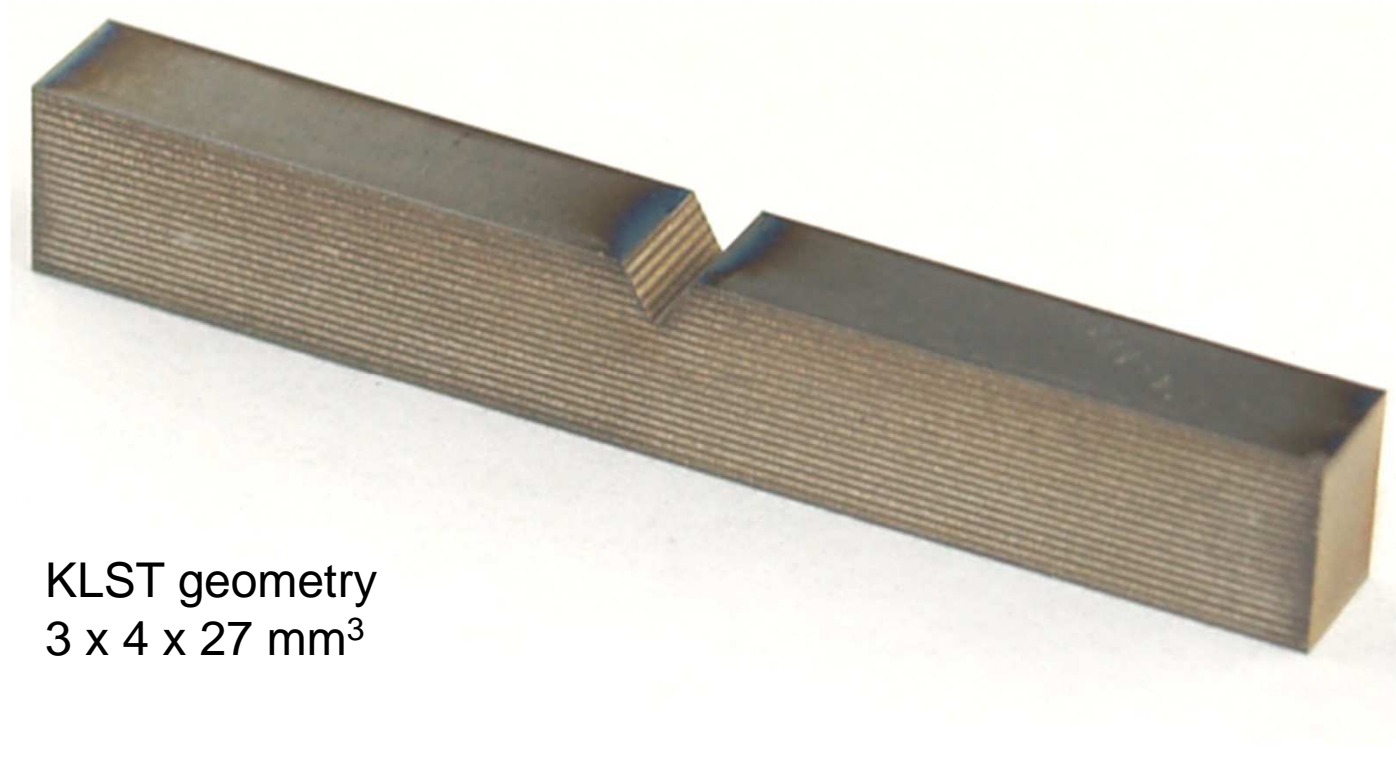
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W-laminate: microstructure

The mechanical properties of a W-laminate depend on

- the condition of the W-foil as well as
- the interface

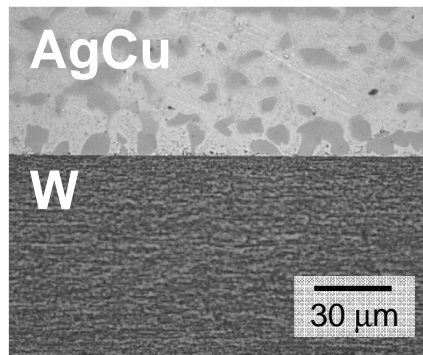
after the joining process.



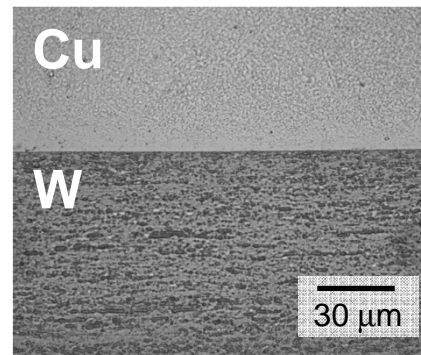
KLST geometry
3 x 4 x 27 mm³

W-laminate: microstructure

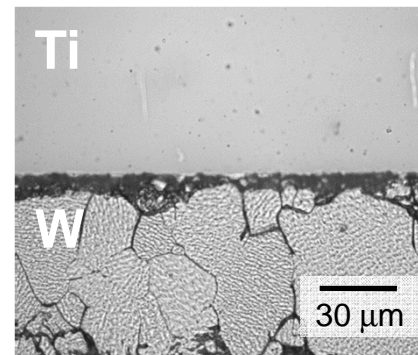
- Condition of the W-foil:
 - As-received
 - Recrystallized
- Condition of the interface:
 - Wettability
 - Solid solution
 - Intermetallic compounds



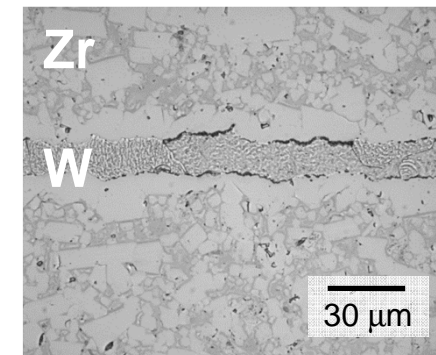
$$T_S^{\text{AgCu}} = 780^\circ\text{C}$$



$$T_S^{\text{Cu}} = 1085^\circ\text{C}$$



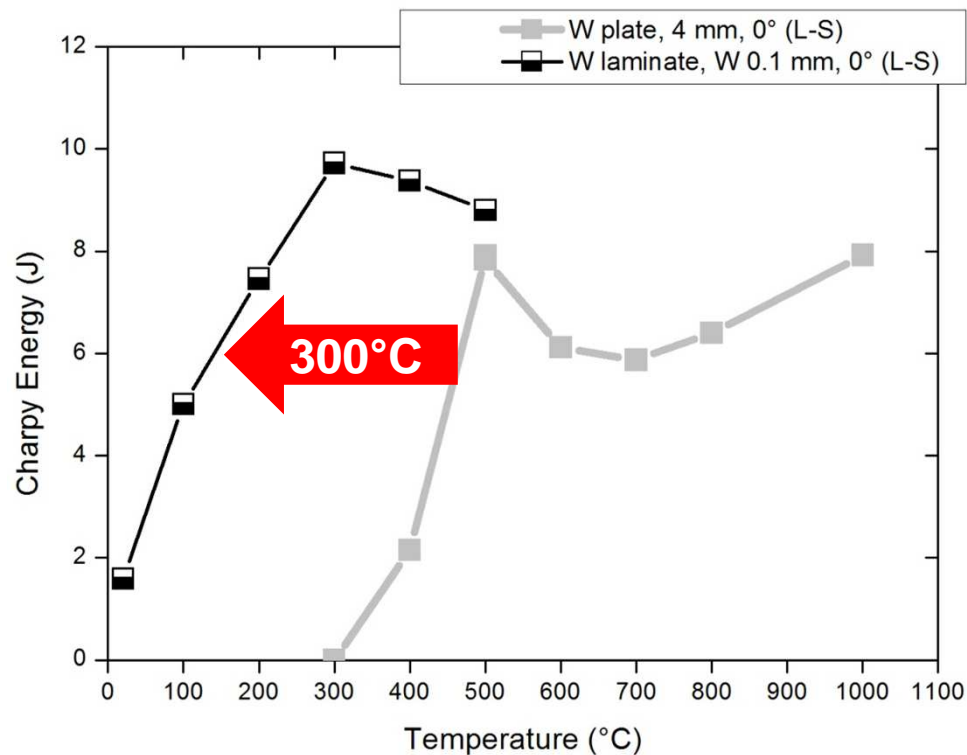
$$T_S^{\text{Ti}} = 1670^\circ\text{C}$$



$$T_S^{\text{Zr}} = 1855^\circ\text{C}$$

W-laminates: Charpy impact tests

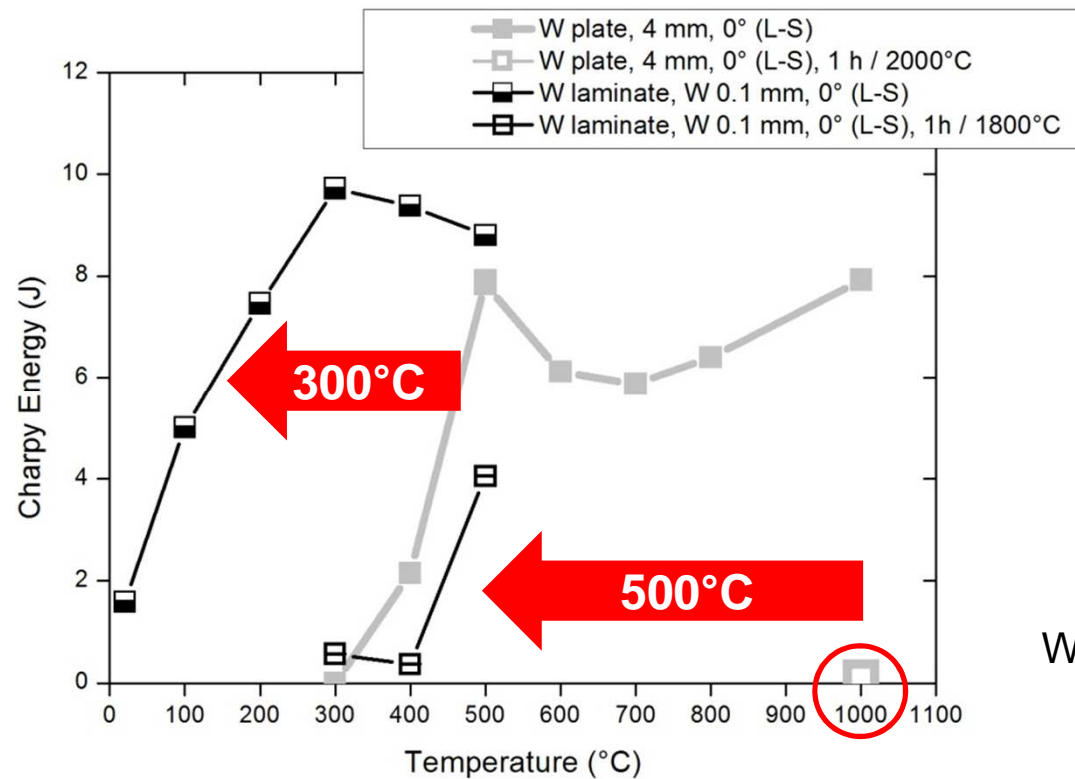
- Can the ductile properties of a W-foil be transferred to the bulk?
 - As-received: improvement of 300°C



W-laminate made of AgCu

W-laminates: Charpy impact tests

- Can the ductile properties of a W-foil be transferred to the bulk?
 - As-received: improvement of 300°C
 - Recrystallized: improvement of 500°C

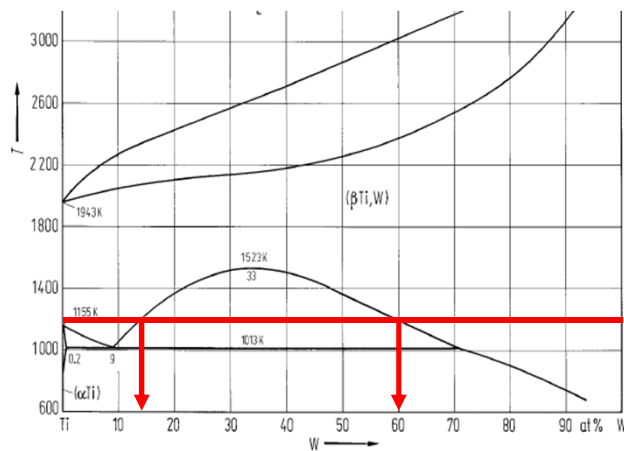


W-laminate made of AgCu

W-laminates: diffusion bonding with Ti

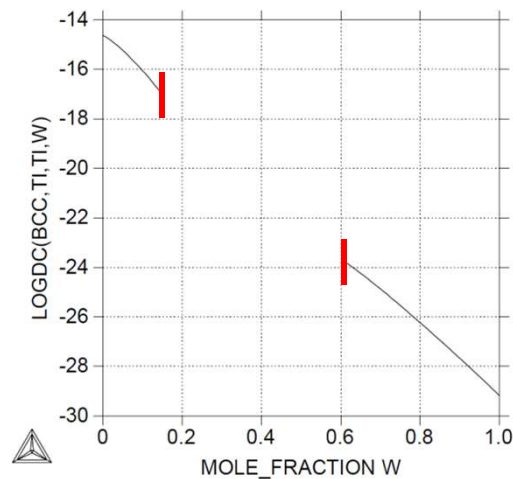
■ W-Ti diffusion bonding at 900°C

W-Ti phase diagram



- 2 solid solutions after cooling down

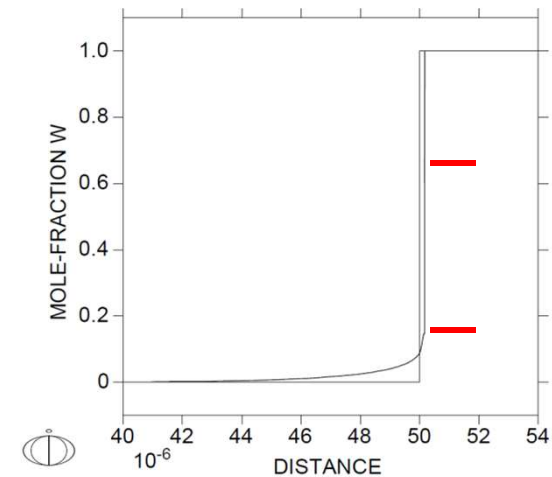
(inter-) diffusion coefficients at 900°C



P. Franke (KIT)

- Diffusion: W in Ti > Ti in W

Interface, 900°C:
0 s, 1 h

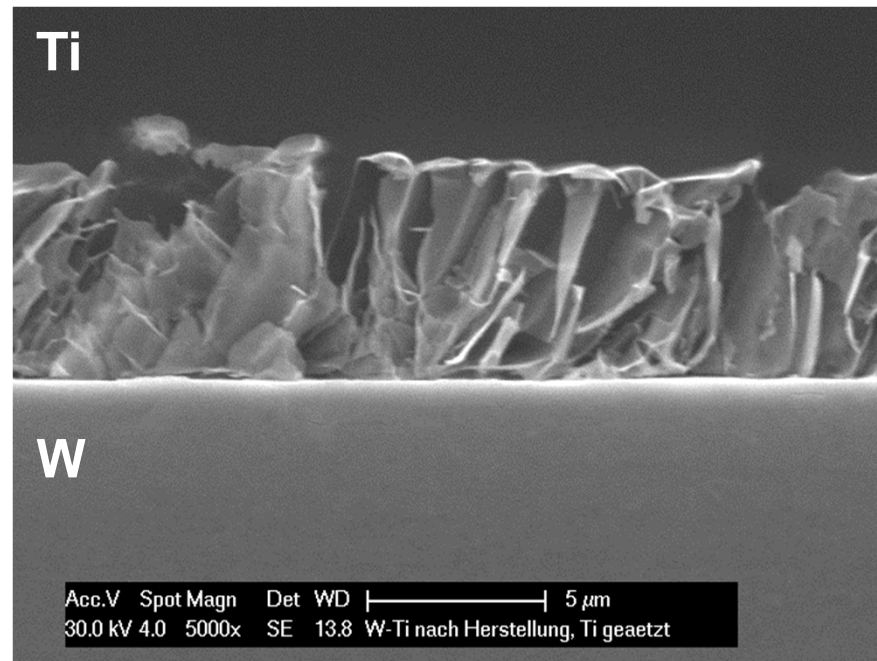


P. Franke (KIT)

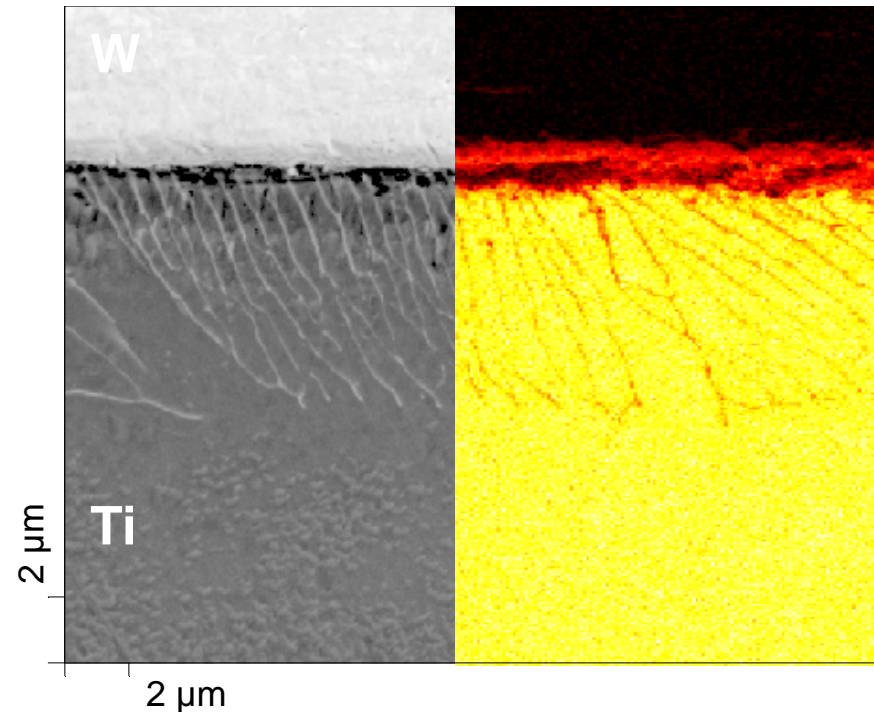
- Phase boundaries
- Miscibility gap

W-laminates: diffusion bonding with Ti

- W-Ti diffusion bonding at 900°C → cooling down at RT



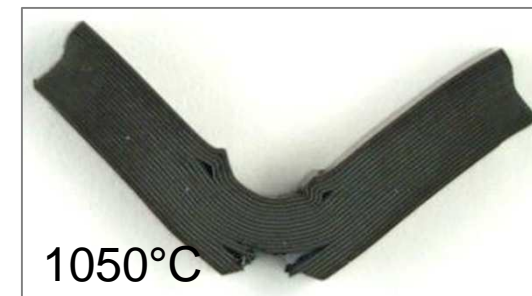
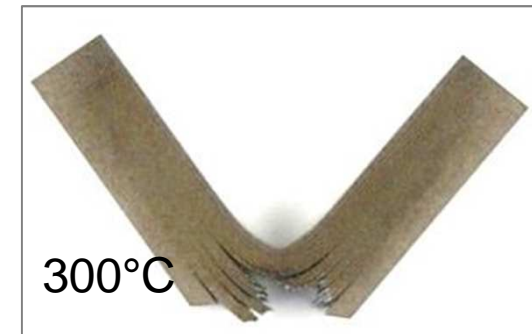
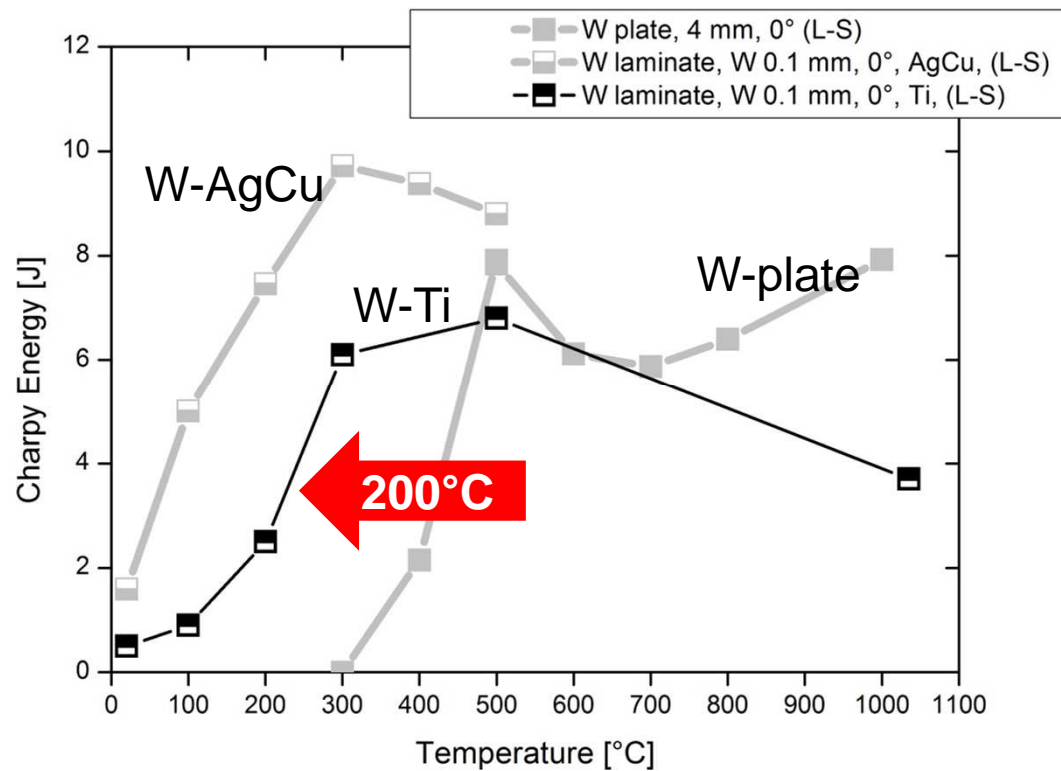
- Eutectoid transformation
- WIDMANSTÄTTEN-kind structure
- β -Ti needles in α -Ti matrix



- Quantitative scale of Ti: yellow = max., black = min.

W-laminates: diffusion bonding with Ti

- Charpy impact properties
 - Improvement of 200°C compared to W-plate material

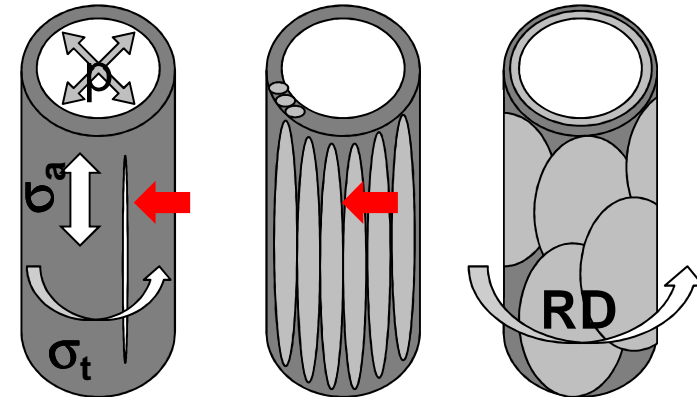


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W-laminates: pipes

- How can a tungsten pipe be produced?
 - Extrusion → very challenging
 - Drilling a hole in a rod
 - **NEW: by rolling up a W-foil**



15 mm

rod



AgCu, 780°C



Cu, 1085°C



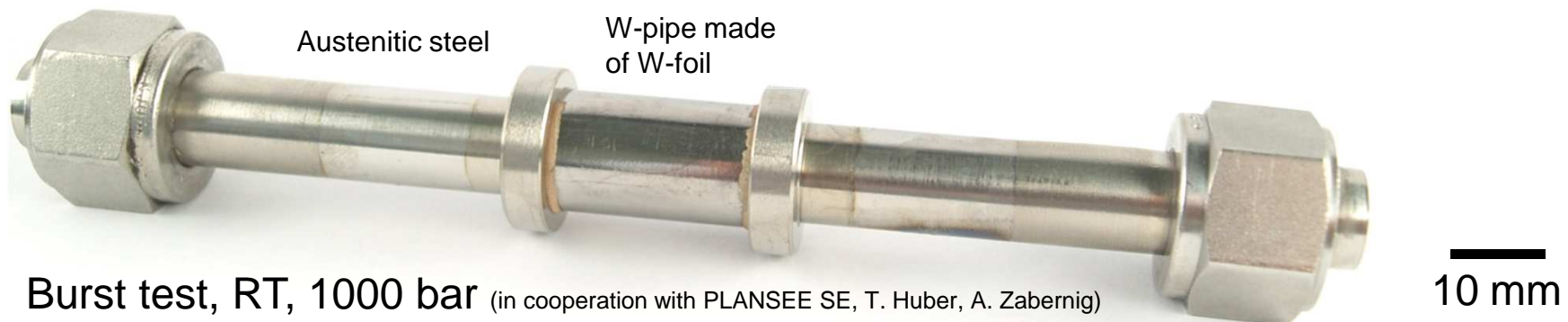
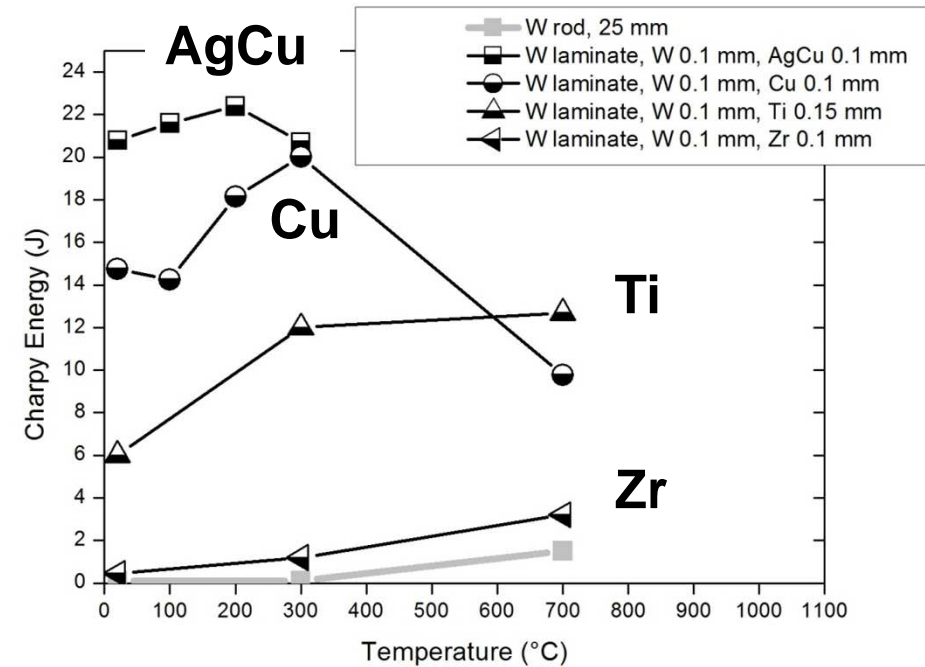
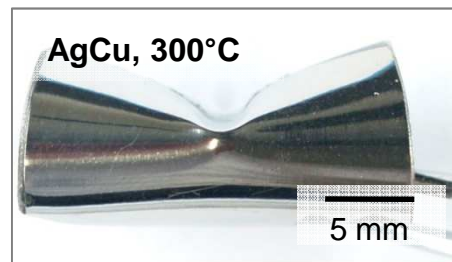
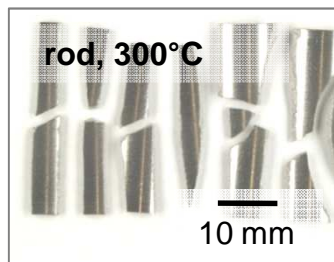
Ti, 1670°C



Zr, 1855°C

W-laminates: pipes

- Characterization by
 - Charpy impact tests
 - Burst test



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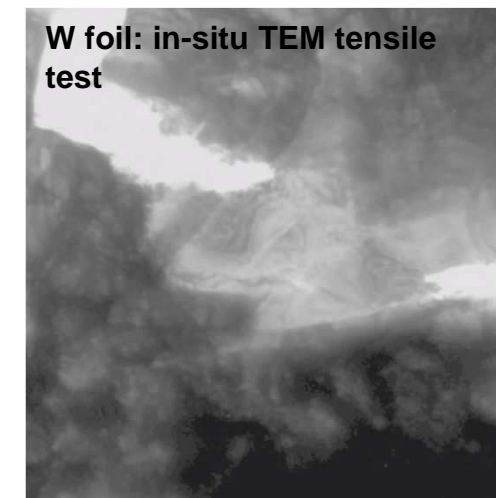
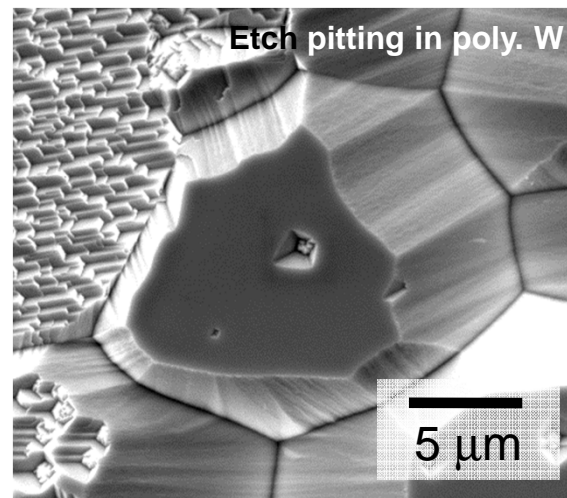
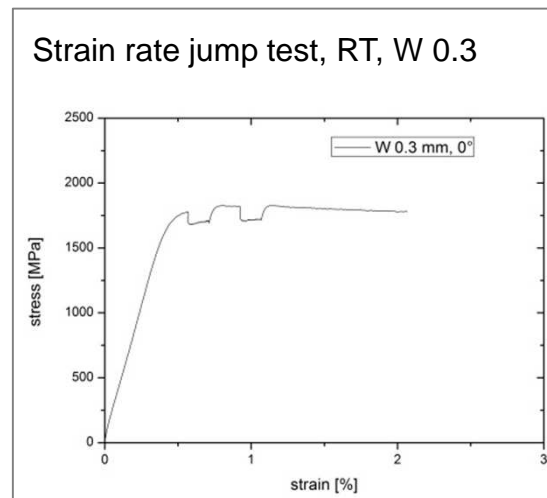
Scientific outlook: ductility and toughness

■ Ductility:

- Direct: TEM
- Indirect: SRS, V = fingerprints of the kinetics of pl. deformation

■ Toughness:

- Direct: TEM
- Indirect: $\Delta H_{\text{BDT}} (K_{\text{IQ}})$ vs. ΔH_{kp} vs. ΔH_{d}



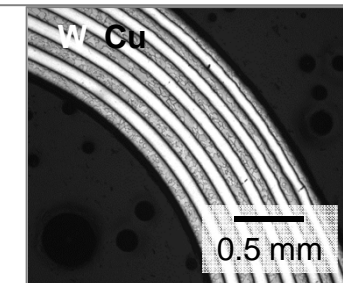
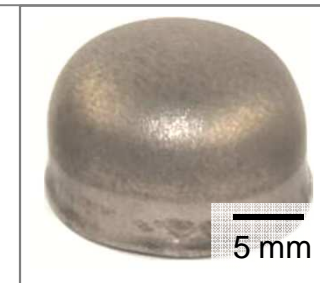
M. Klimenkov, U. Jäntsch (KIT)

Technical outlook: HHF applications

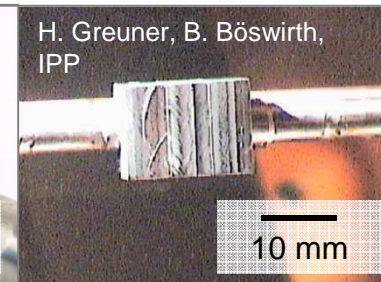
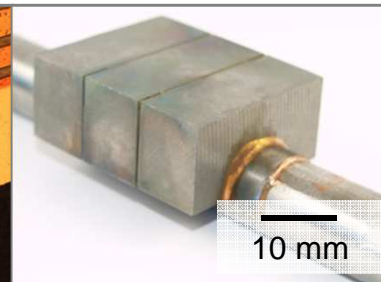
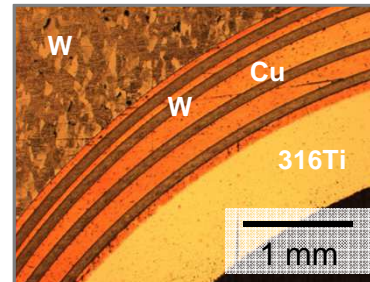
- W-laminates for water- and helium-cooled divertors and CSP



W-laminate plate:
deep drawing

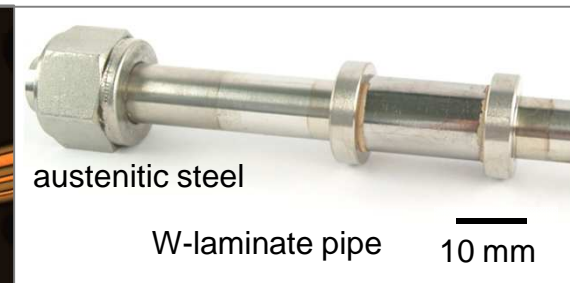
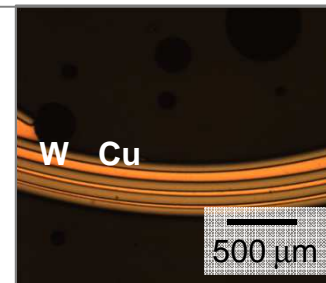


W-laminate plate:
interlayer



H. Greuner, B. Böswirth,
IPP

W-laminate pipe:
structural part



austenitic steel

W-laminate pipe

Thank you for your attention

The authors are grateful to:

PLANSEE SE,
University of Oxford,
EFDA and
our colleagues from IAM (KIT).

