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

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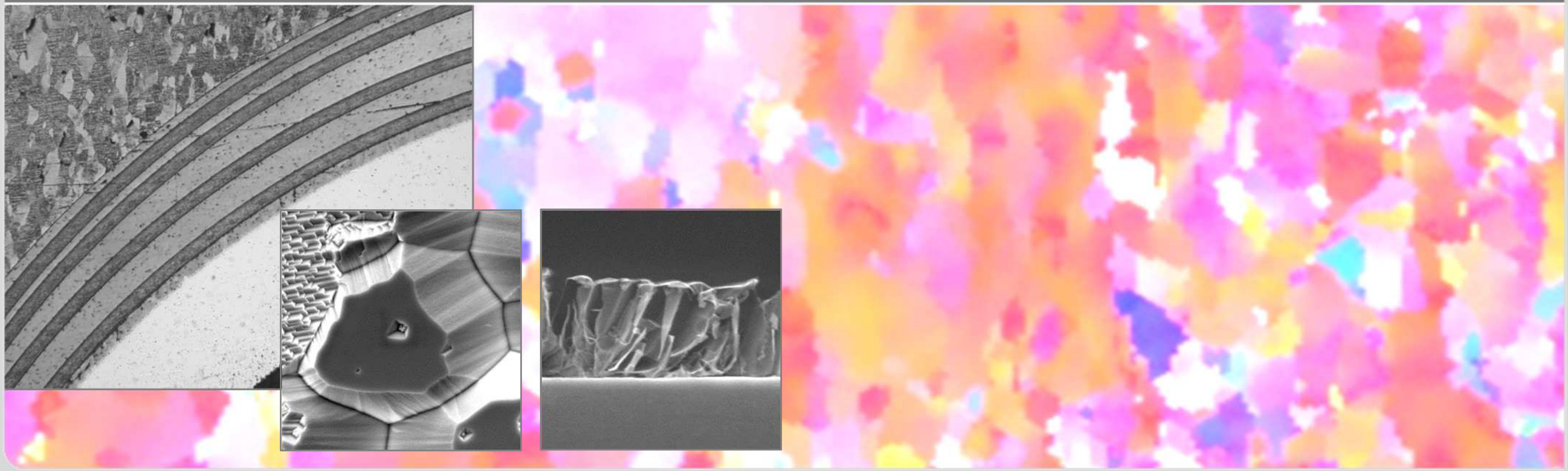
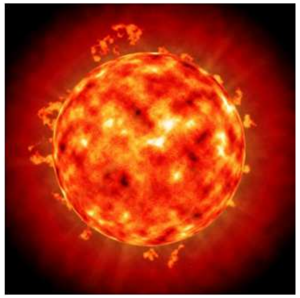
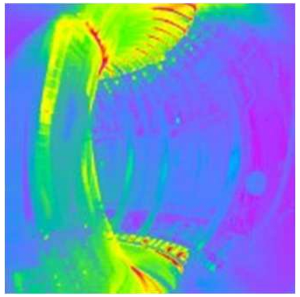


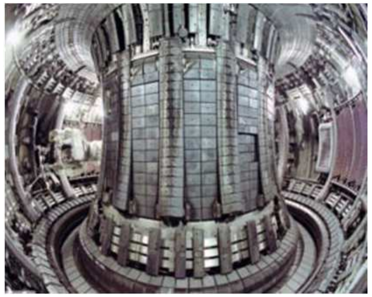
What is the problem?

- 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°C)
- Disadvantages:
  - Low fracture toughness, K_{IC} [MPa $m^{1/2}$]
  - High brittle-to-ductile transition temperature (BDTT)





picture: ITER

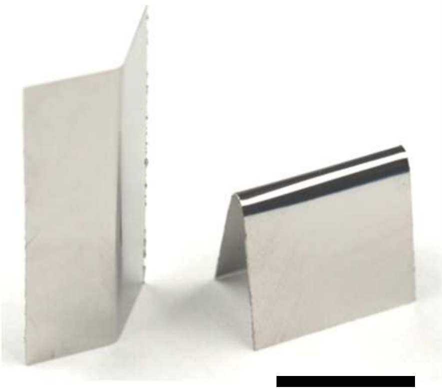


Tokamak fusion reactor

picture: PLANSEE SE

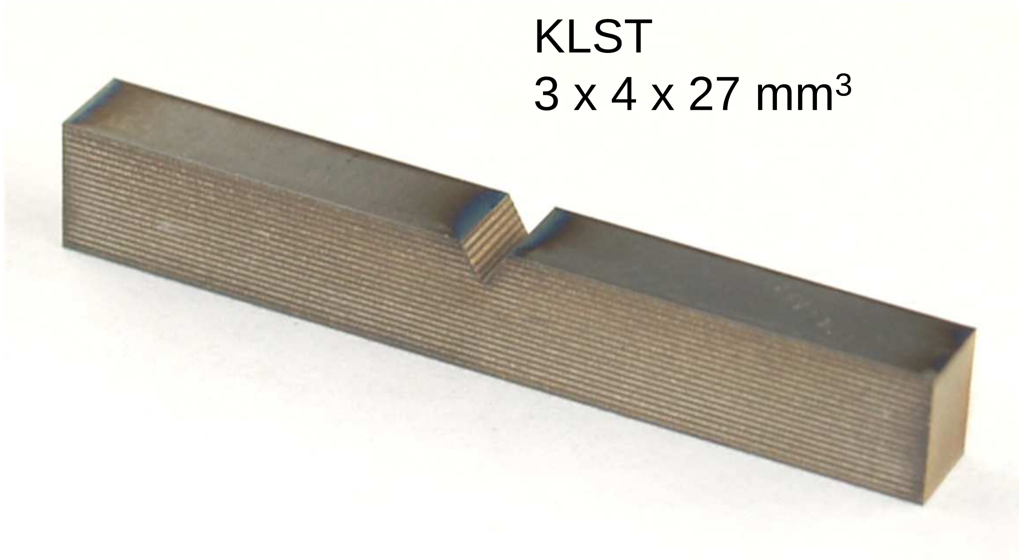
Main question

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



10 mm

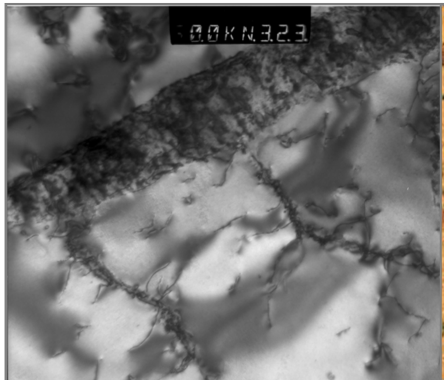
?

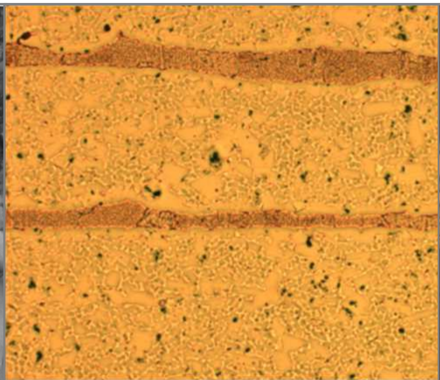


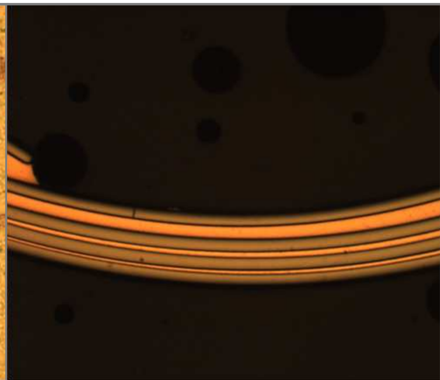
KLST
3 x 4 x 27 mm^3

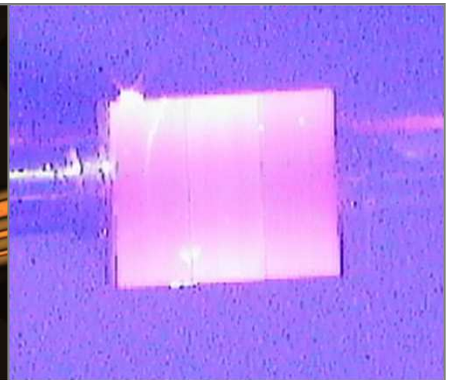
Contents

- 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


W-foil


W-laminat plate


W-laminate pipe


application

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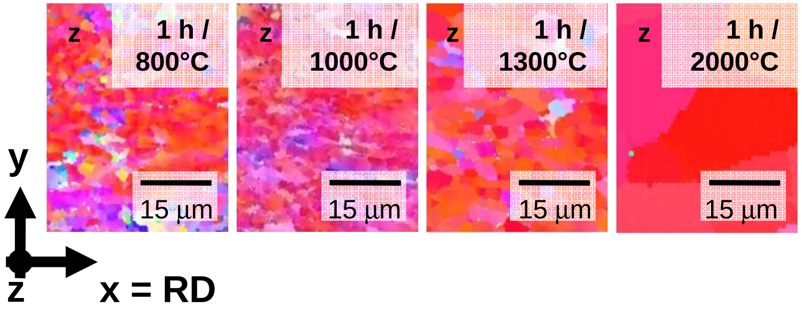
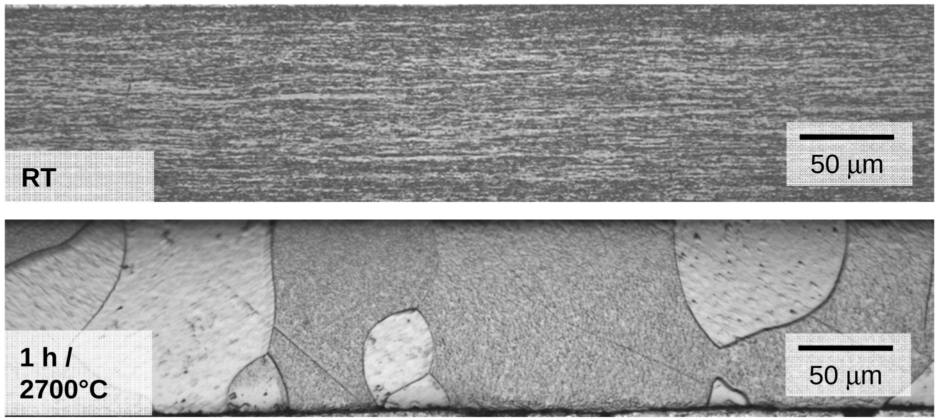
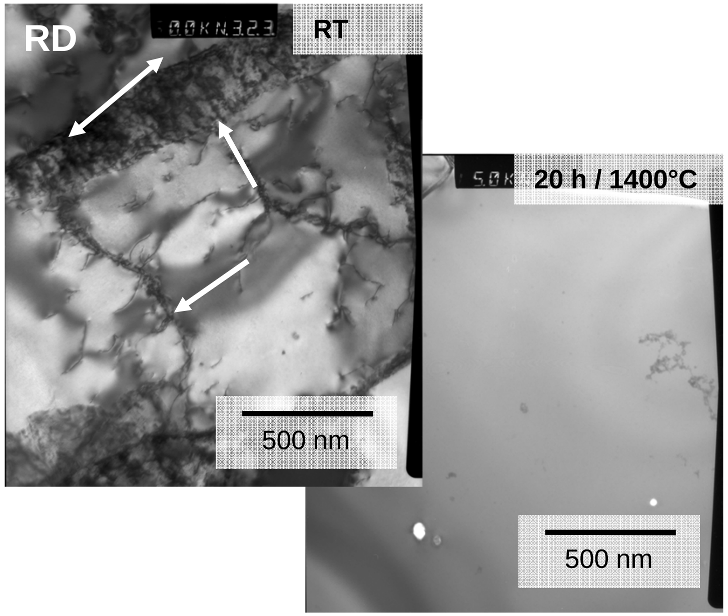
Microstructure of W-foil, 100 μm

- Grain size:
  - As-received: 0.5 x 3 x 15 μm^3
  - 1 h / 2700°C: 100 x 100 x 100 μm^3
- Texture: {100} <011> ; rotated cube
- Sub grains: nearly free from disl.
- Begin rxx: 1200°C

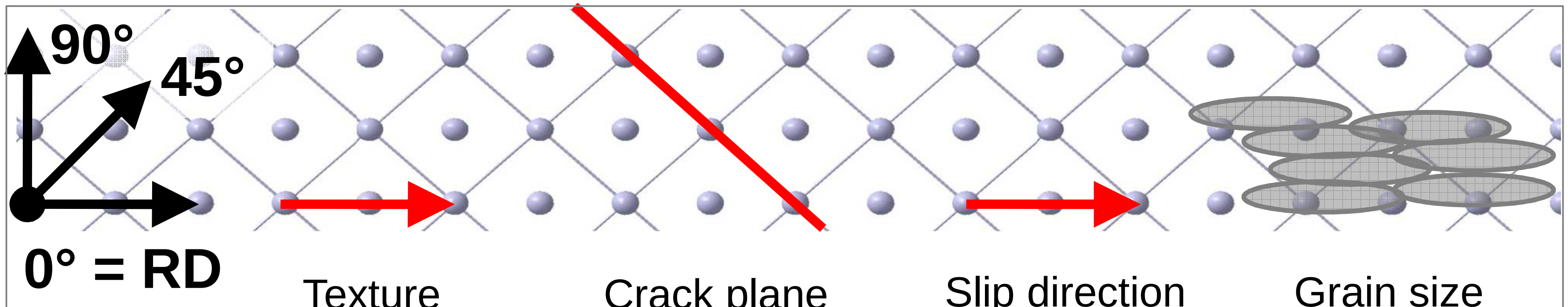
(pictures: J. Reiser, Y. Xiaoou, D.E.J. Armstrong)







3PB-tests on W-foil, 100 μm

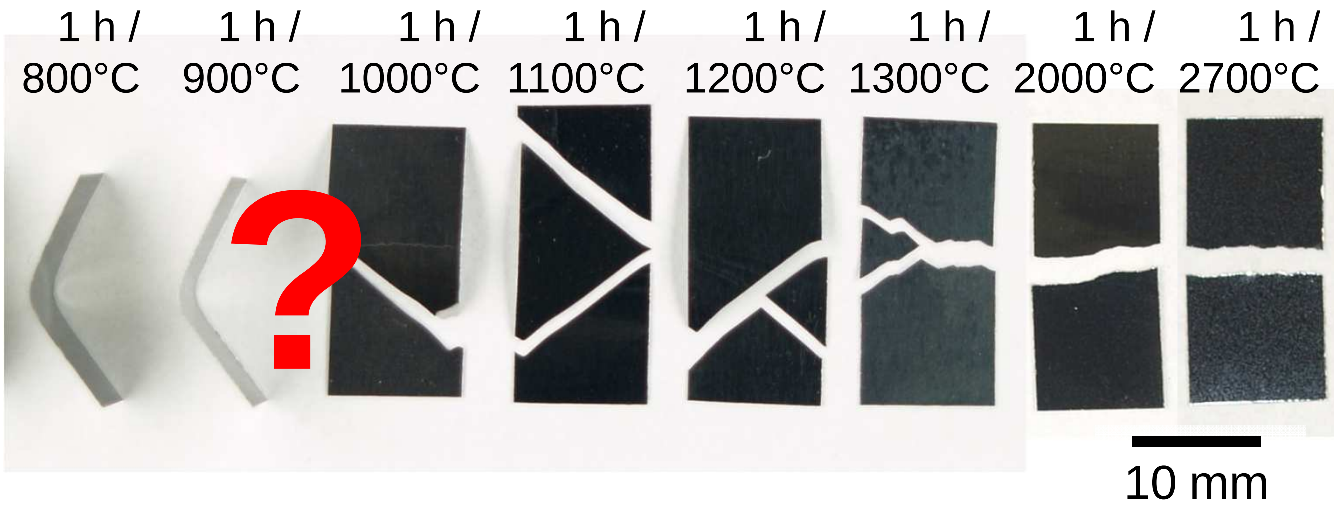


Texture
{100} <011>

Crack plane
{100}

Slip direction
<111>

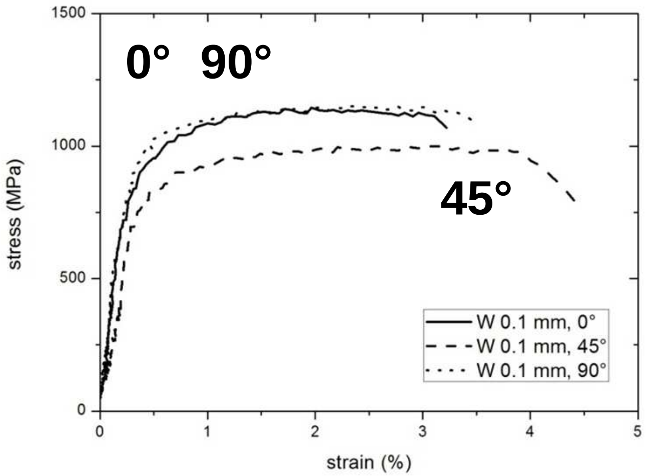
Grain size
0,5 x 3 x 15 μm^3



3 point bending test at RT

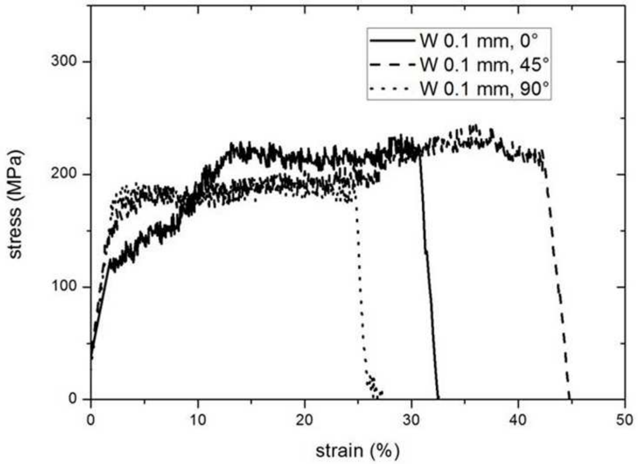
Tensile tests on W-foil, 100 μm

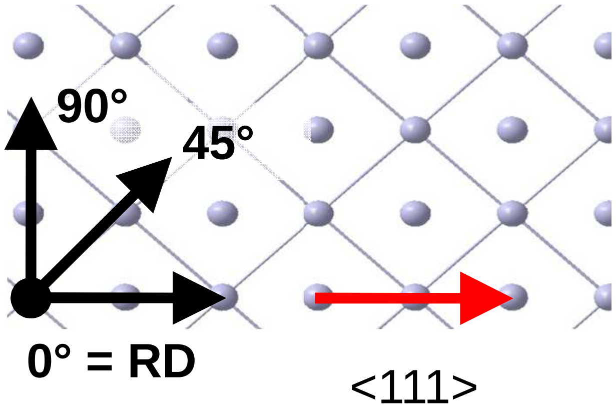
As-received, 600°C	1 h / 2000°C, 600°C

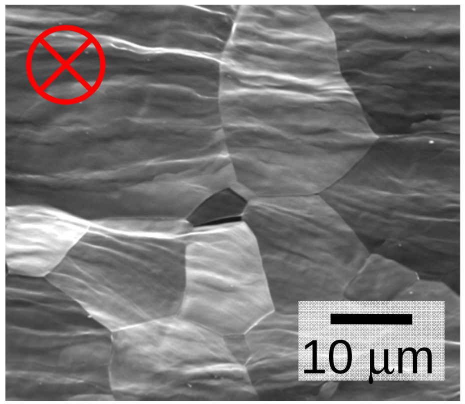


As-received

1 h / 2000°C







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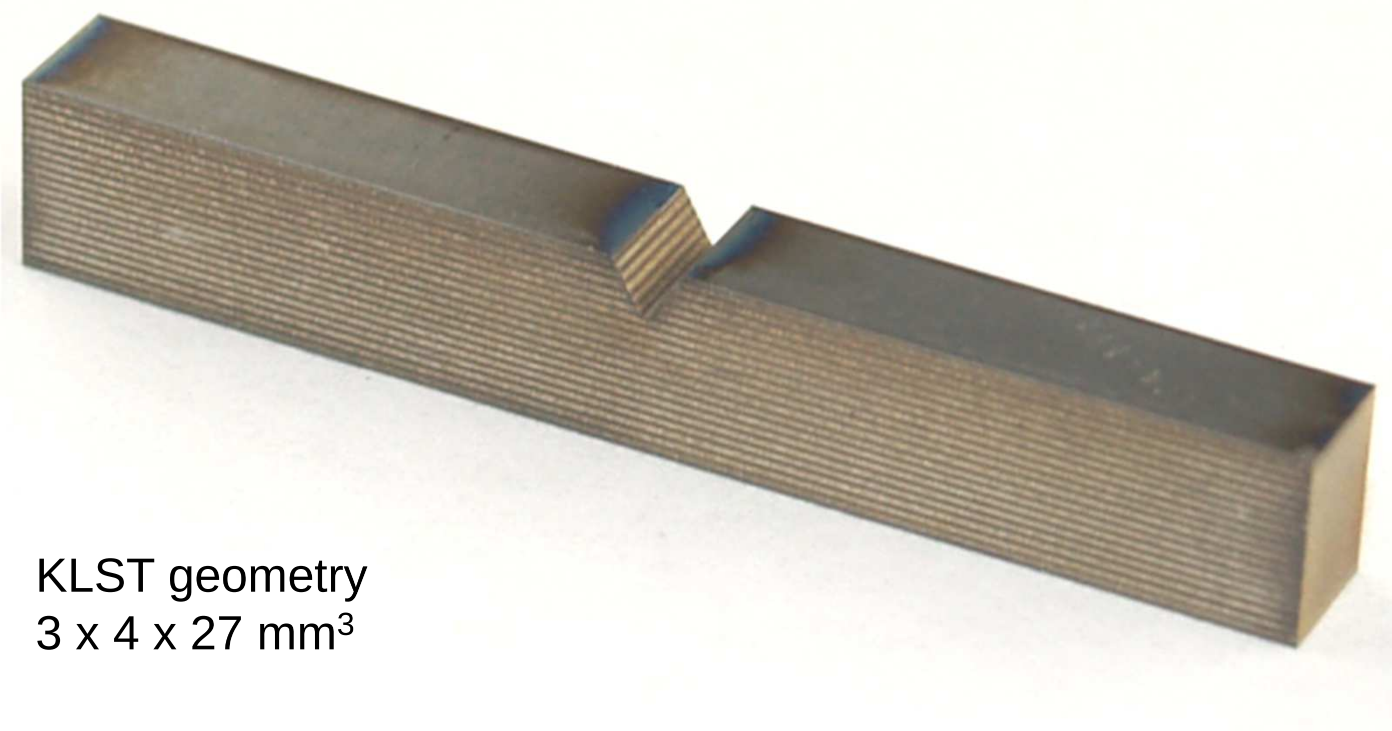
W-laminate: microstructure

The mechanical properties of a W-laminate depend on

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

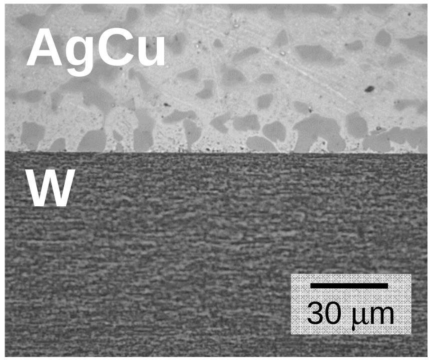
after the joining process.



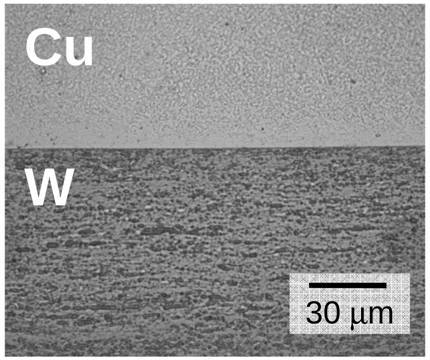
KLST geometry
3 x 4 x 27 mm^3

W-laminate: microstructure

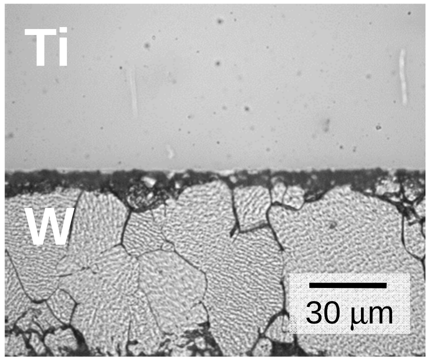
- Condition of the W-foil:
  - As-received
  - Recrystallized
- Condition of the interface:
  - Wettability
  - Solid solution
  - Intermetalic compounds



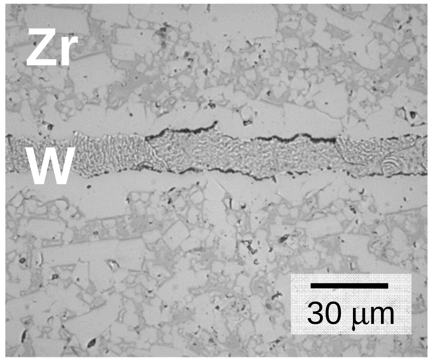
$T_S^{AgCu} = 780°C$



$T_S^{Cu} = 1085°C$



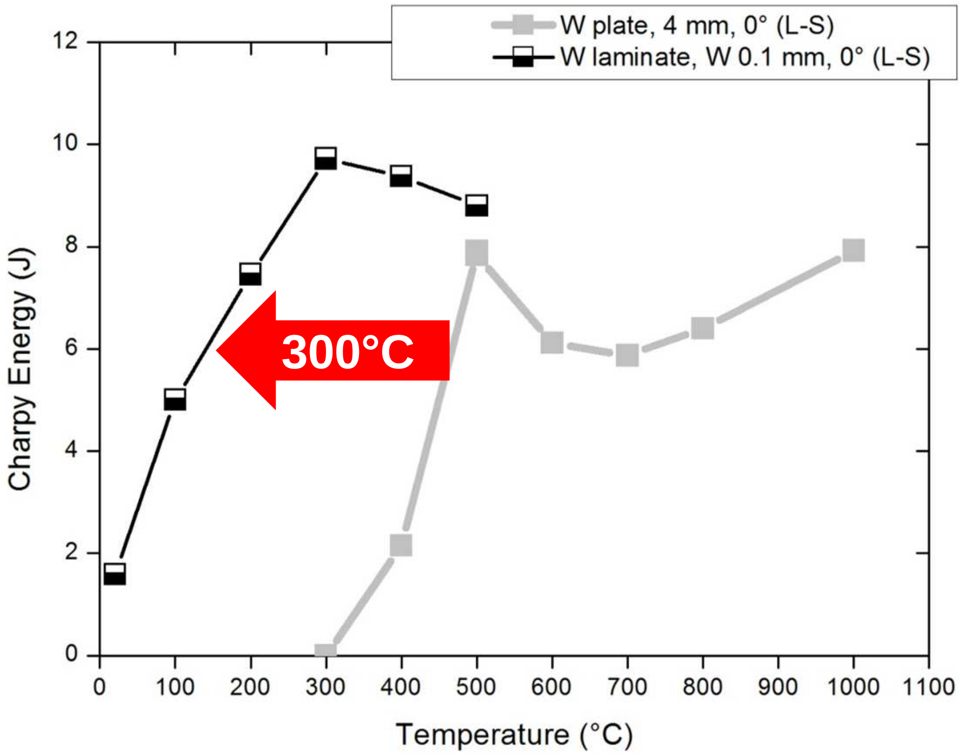
$T_S^{Ti} = 1670°C$



$T_S^{Zr} = 1855°C$

W-laminates: Charpy impact tests

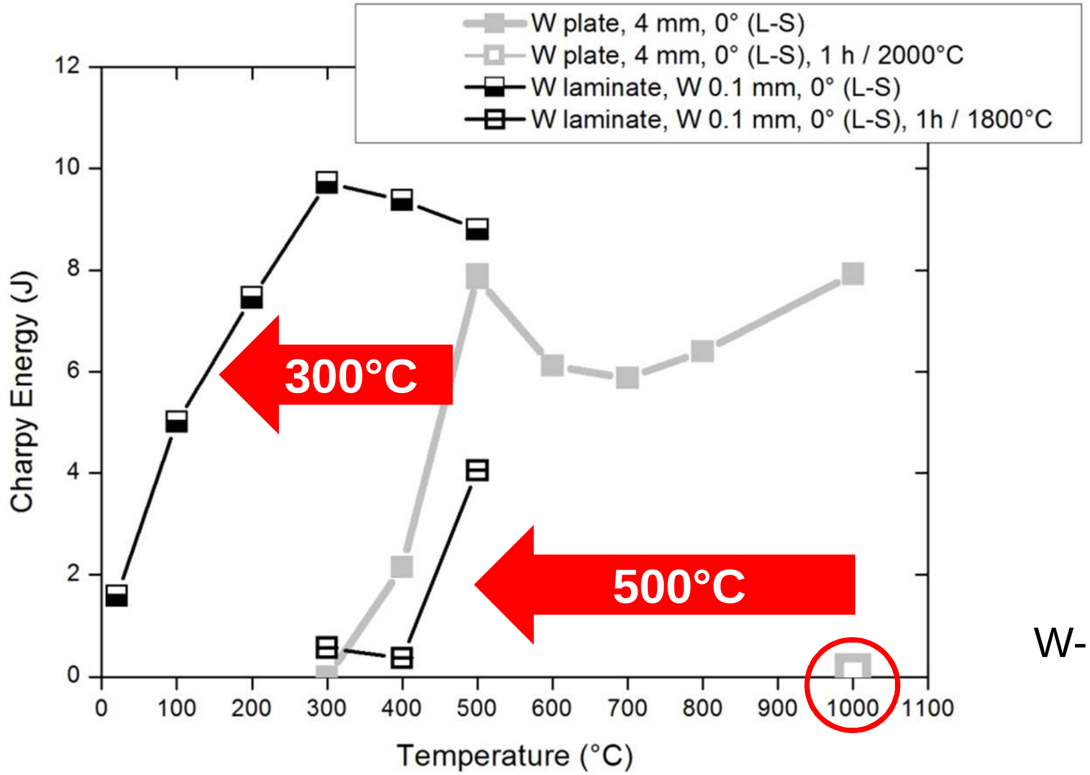
- Can the ductile properties of a W-foil be transferred to the bulk?
  - As-received: improvement of 300°C



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

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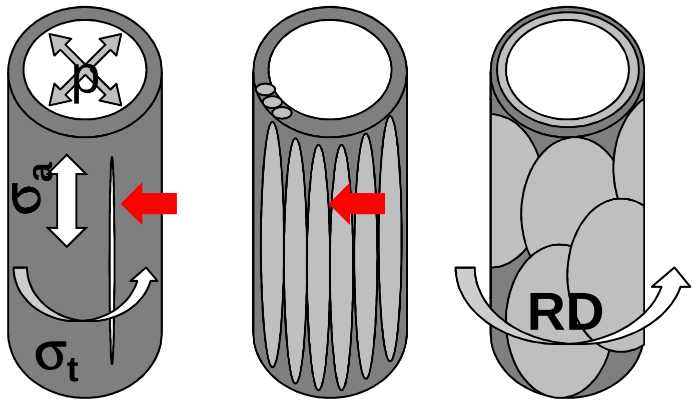
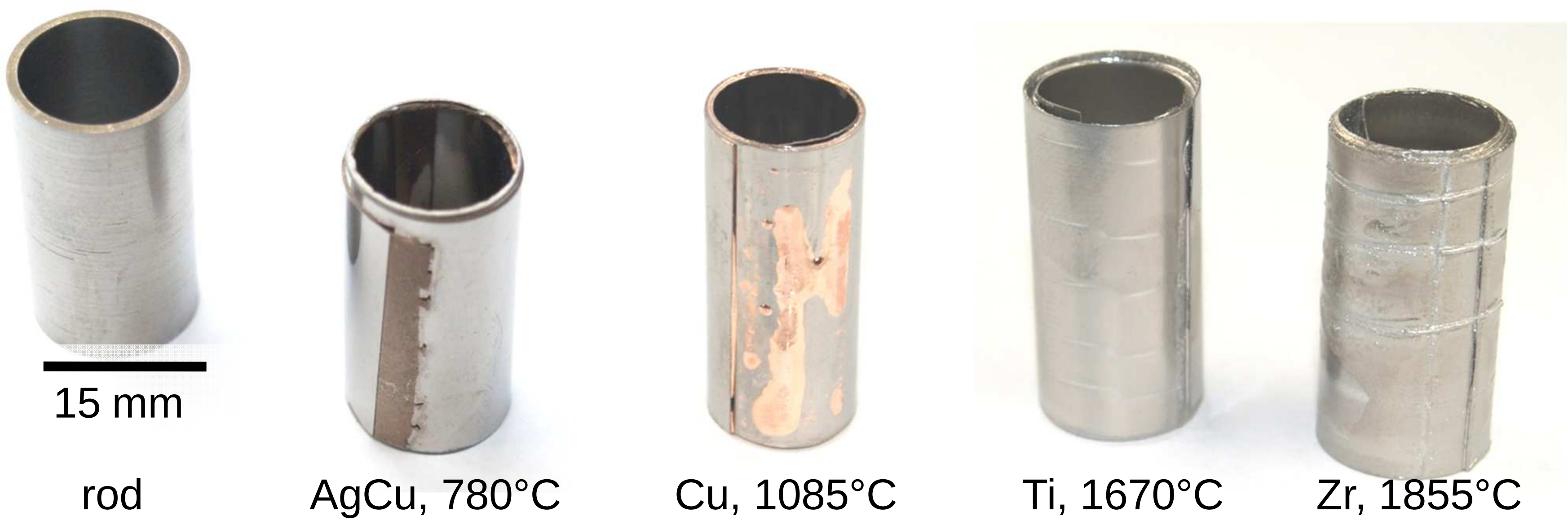
W-laminates: pipes

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





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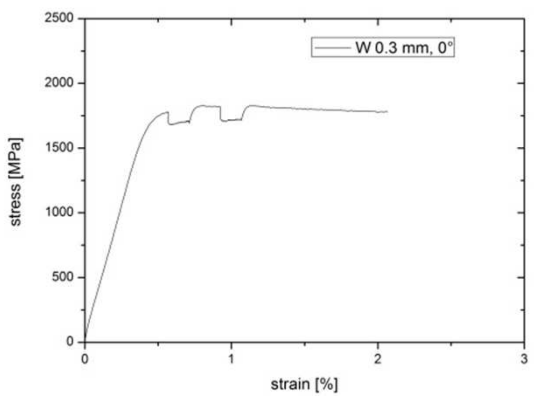
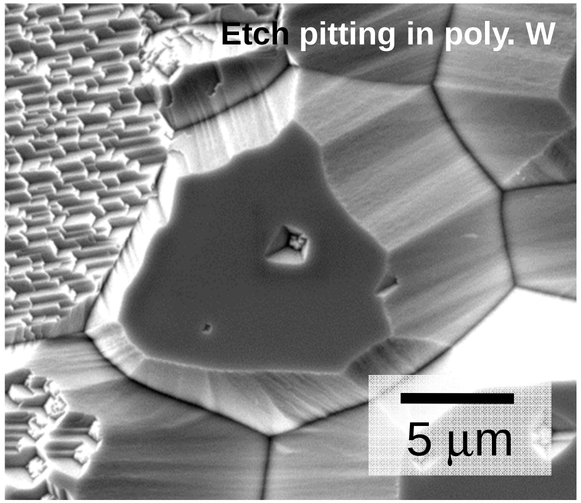
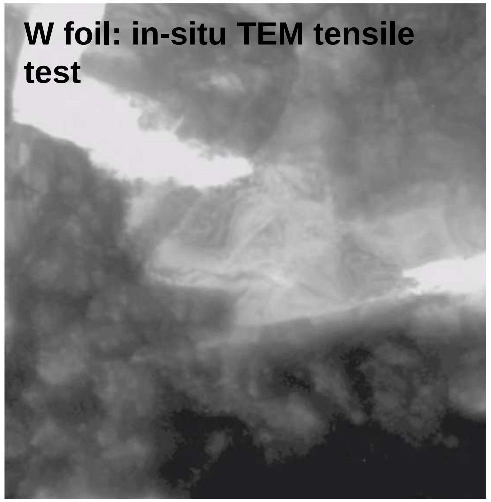
Scientific outlook: ductility and toughness

- Ductility:
  - Direct: TEM
  - Indirect: SRS, V = fingerprints of the kinetics of pl. deformation
- Toughness:
  - Direct: TEM
  - Indirect: ΔH_{BDT} (K_{IQ}) vs. ΔH_{kp} vs. ΔH_d

Strain rate jump test, RT, W 0.3





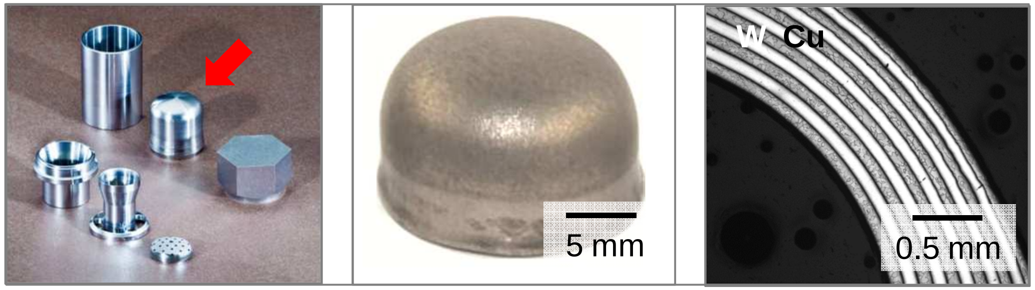


M. Klimenkov, U. Jäntsch (KIT)

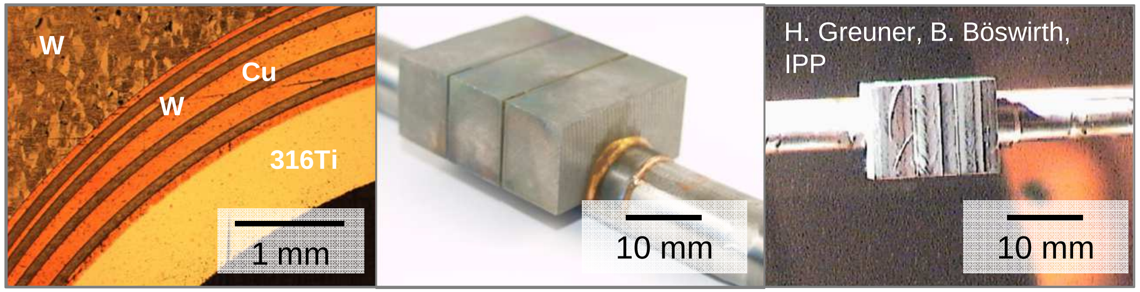
Technical outlook: HHF applications

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

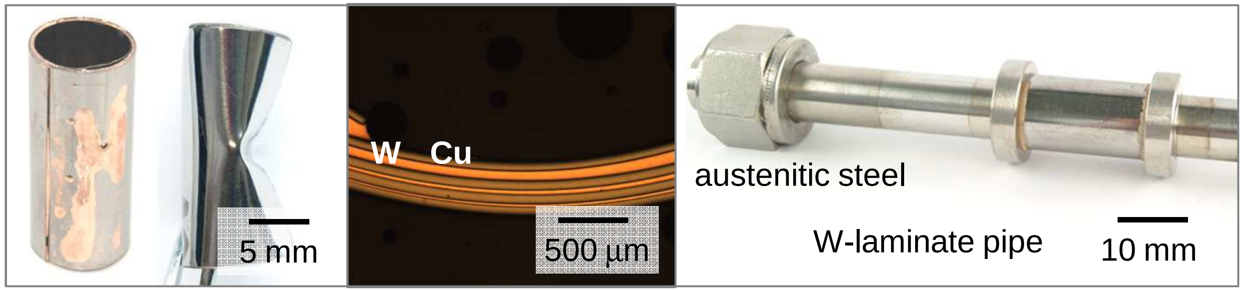
W-laminate plate: deep drawing



W-laminate plate: interlayer



W-laminate pipe: structural part



Thank you for your attention

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