

Tungsten (W) foil laminates for structural divertor applications

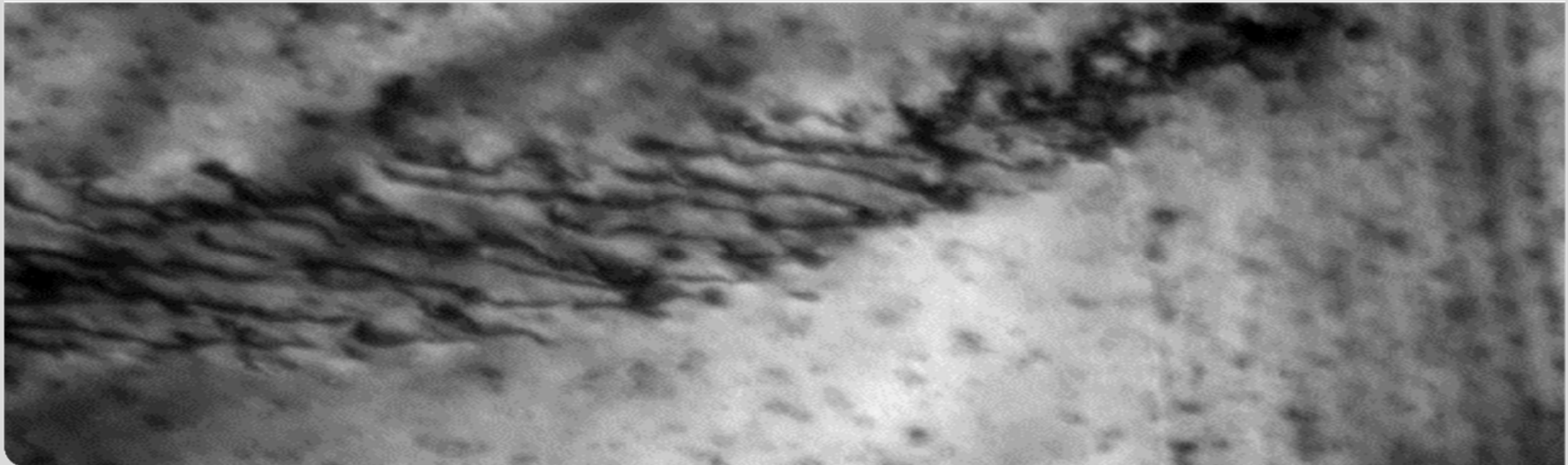
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INSTITUTE FOR APPLIED MATERIALS, APPLIED MATERIALS PHYSICS



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- Introduction
- W plates and foils
- W foil laminates
- W foil laminate pipes

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- **Introduction**
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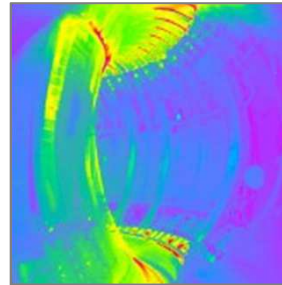
What is the problem?

- Divertor applications ask for advanced **structural** high temperature materials
- Tungsten (W)
 - Advantage: $T_m = 3422^\circ\text{C}$ (3695 K)
 - Disadvantage: brittleness, BDT

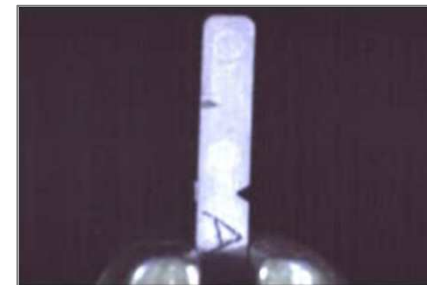
→ How to make tungsten ductile?



Wendelstein 7-X, Greifswald,
Germany (C. Lünig)



picture: ITER



Ductilisation of tungsten (W)

■ Definition

- Decrease of the BDT temperature
- Increase of K_{IQ} , (R-curve behaviour)
- Tensile test: increase of elongation at break

■ Approaches

- Modification of the microstructure through cold-rolling
- Synthesis of a W-laminate (multi-layer material)

■ Discussion

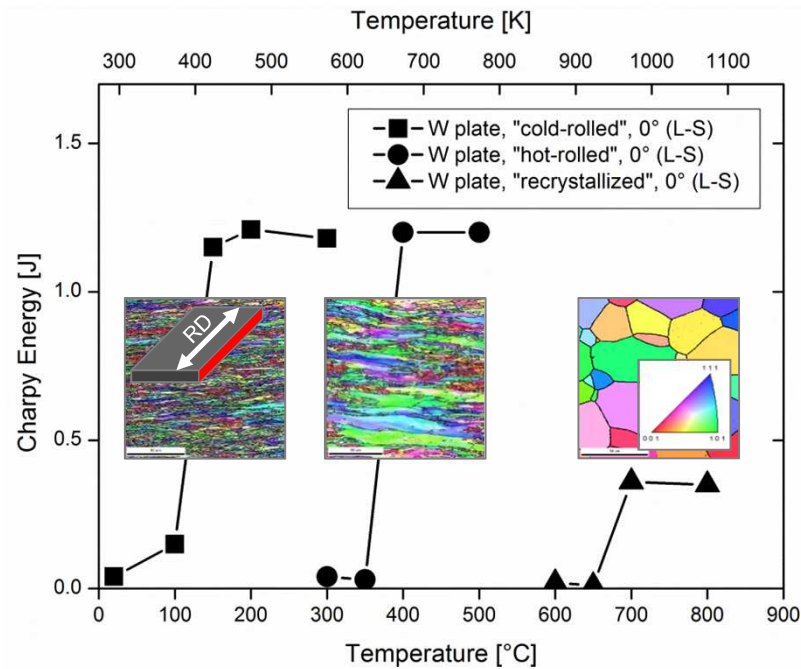
- Dislocations
- Texture
- Microcracking and crack bridging
- Impurities and sinter pores
- Size effects

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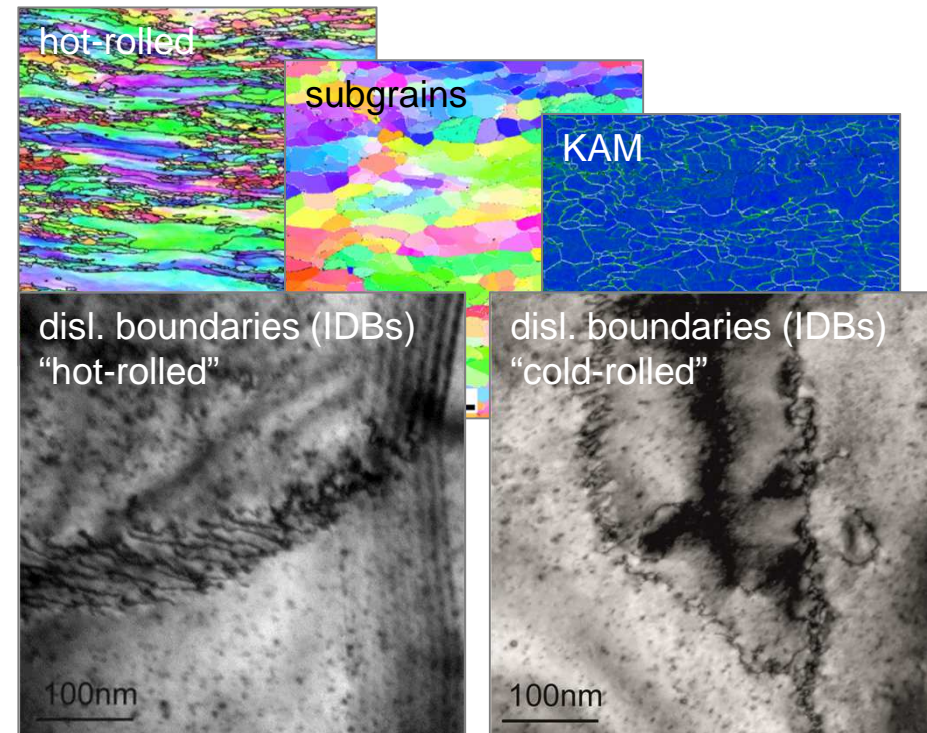
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- **W plates and foils**
 - **BDT**
 - **K_{IQ} , R-curve**
 - **Tensile behaviour**
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W plates and foils: BDT

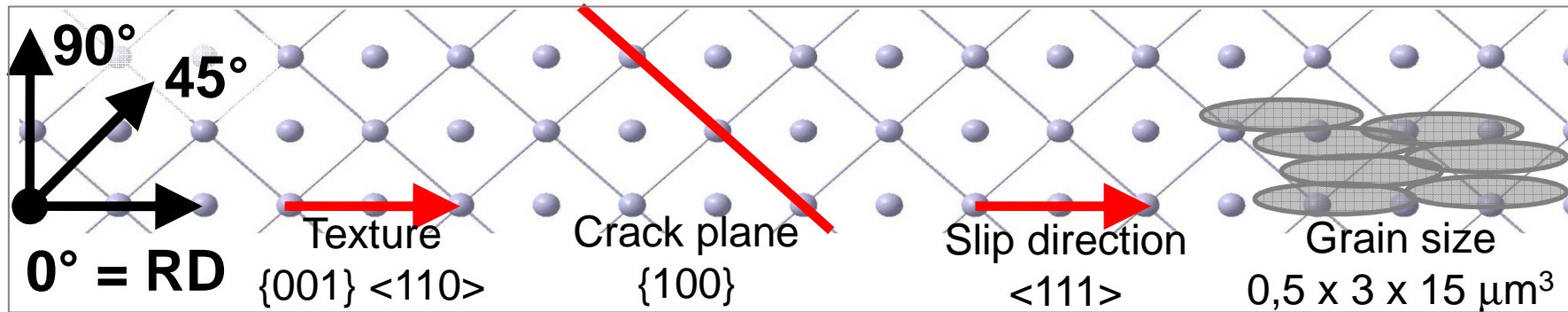
- The BDT temperature decreases through cold-rolling. Why?



- HAGBs, subgrains, disl. density, nature of dislocations, dislocation boundaries

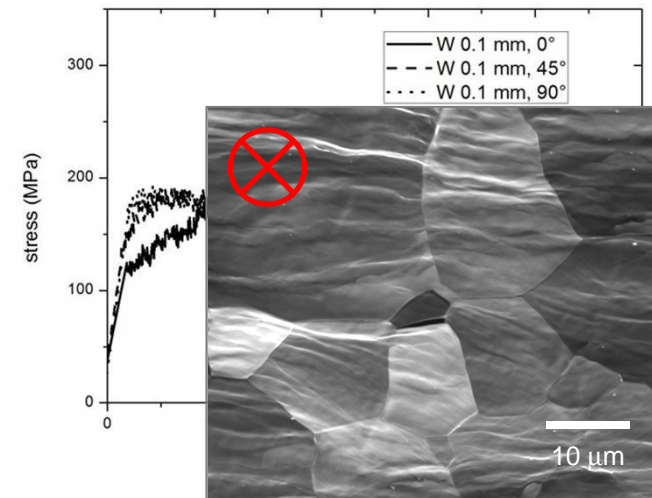
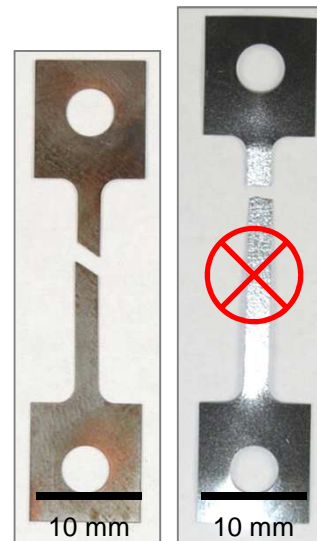
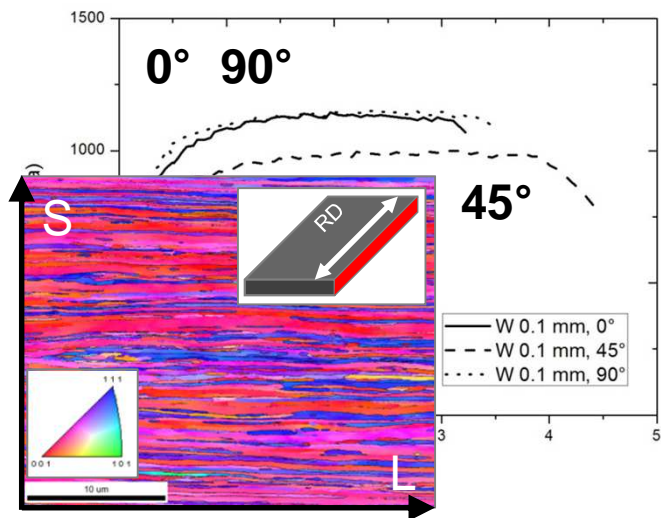


W plates and foils: tensile properties



100 μm , as-received, 600°C

100 μm , 1 h / 2000°C, 600°C



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 - Tensile behaviour
- **W foil laminates**
 - **Charpy impact properties**
 - **Ageing**
- W foil laminate pipes

Ductilisation of tungsten (W)

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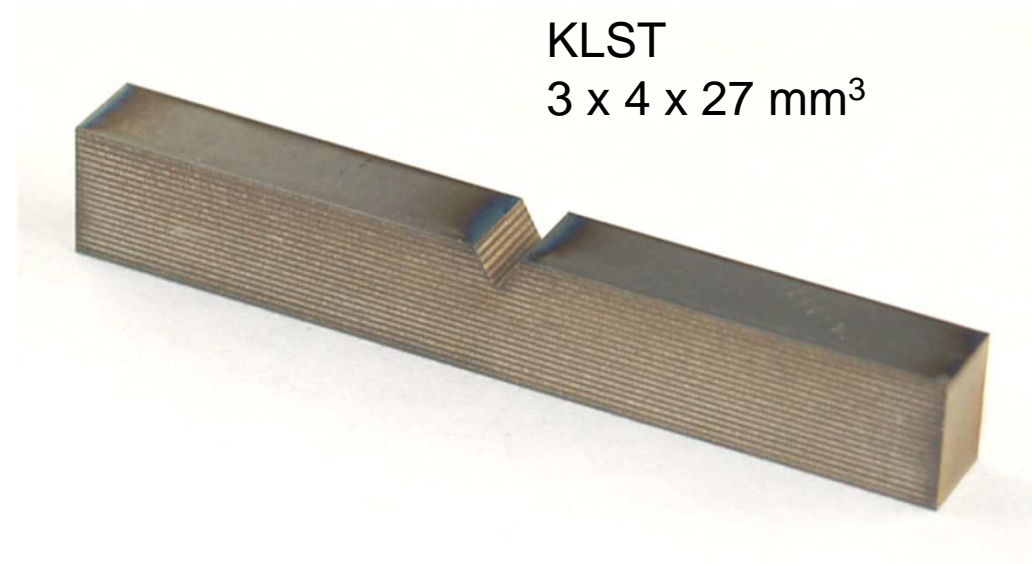
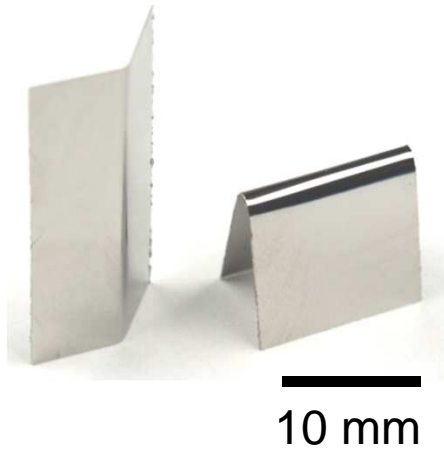
- Modification of the microstructure through cold-rolling
- **Synthesis of a W-laminate (multi-layer material)**

■ Discussion

- Dislocations
- Texture
- Microcracking and crack bridging
- Impurities and sinter pores
- Size effects
- **Creation of surface**
- **Diffusion**
- **Dislocation interface interaction**
- **Residual stresses**
- **Stress redistribution (deviatoric → volumetric)**
- ...

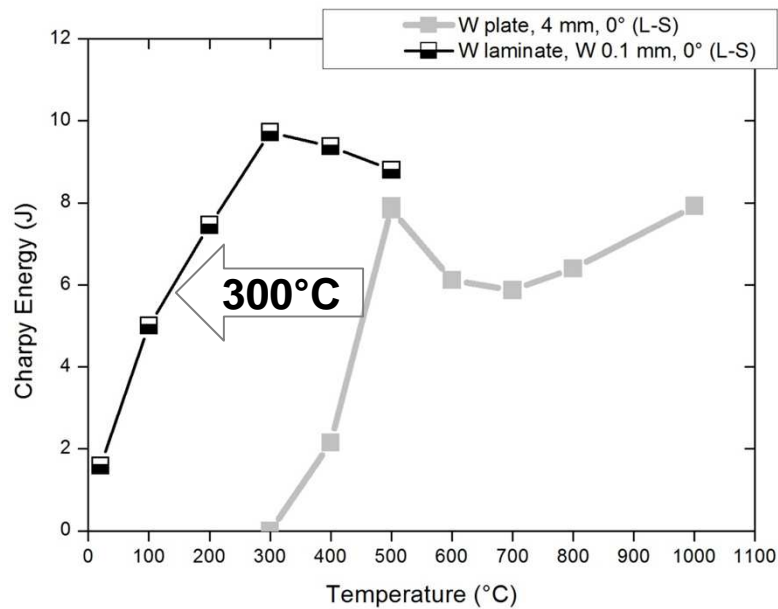
W foil laminates: Charpy properties

- Motivation: bulk material that retains the ductility and toughness of the foils.

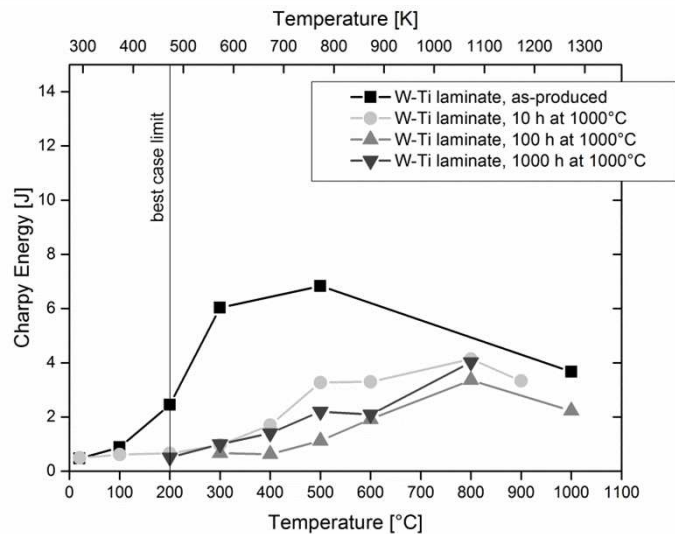
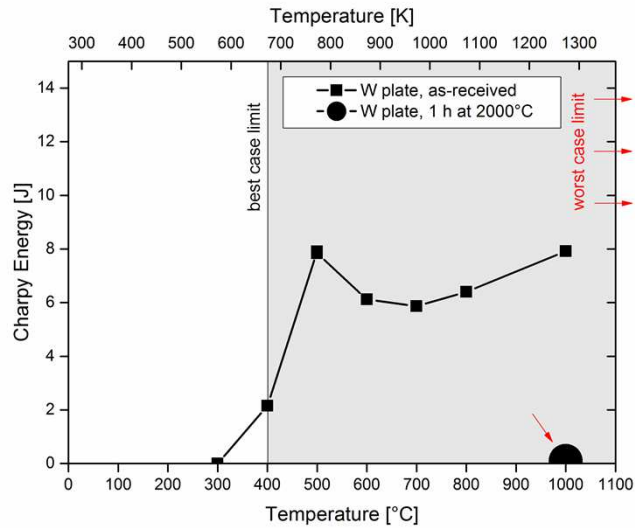


W foil laminates: Charpy properties

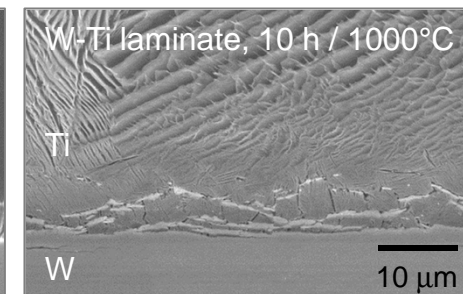
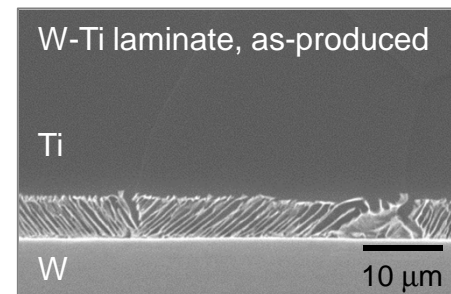
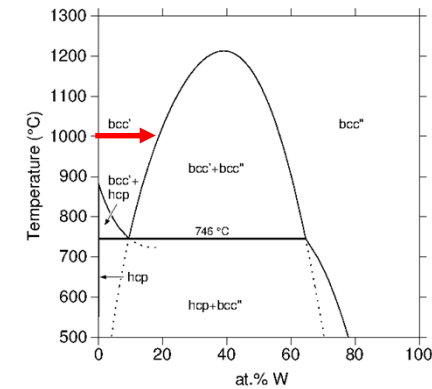
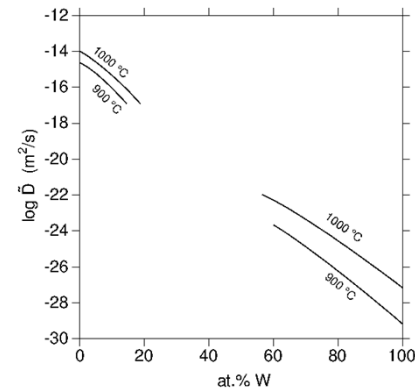
- Motivation: bulk material that retains the ductility and toughness of the foils.
 - As produced: improvement of 300 K



W foil laminates: Ageing – W-Ti



- Ti, hcp/bcc, $T_m = 1668^\circ\text{C}$ (1941 K)
- Diffusion bonded, 1 h / 900°C
- Ageing (10 h, 100 h, 1000 h / 1000°C)

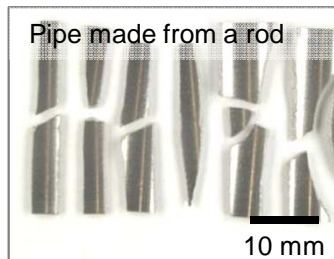


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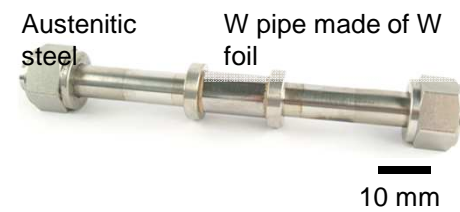
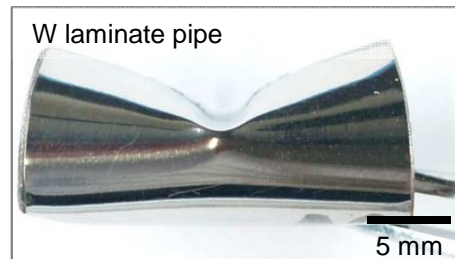
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 - **Mechanical properties (Charpy, burst, HHF tests)**
 - **1000 mm pipe**
 - **Divertor applications**

W foil laminate pipes

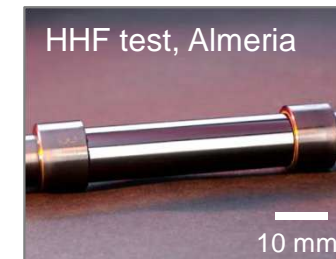
- Characterised by
 - Charp tests
 - Burst test
 - HHF test



Charpy impact test at 300°C



Burst test at RT, 1000 bar, PLANSEE SE



Thank you for your attention

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EUROfusion

