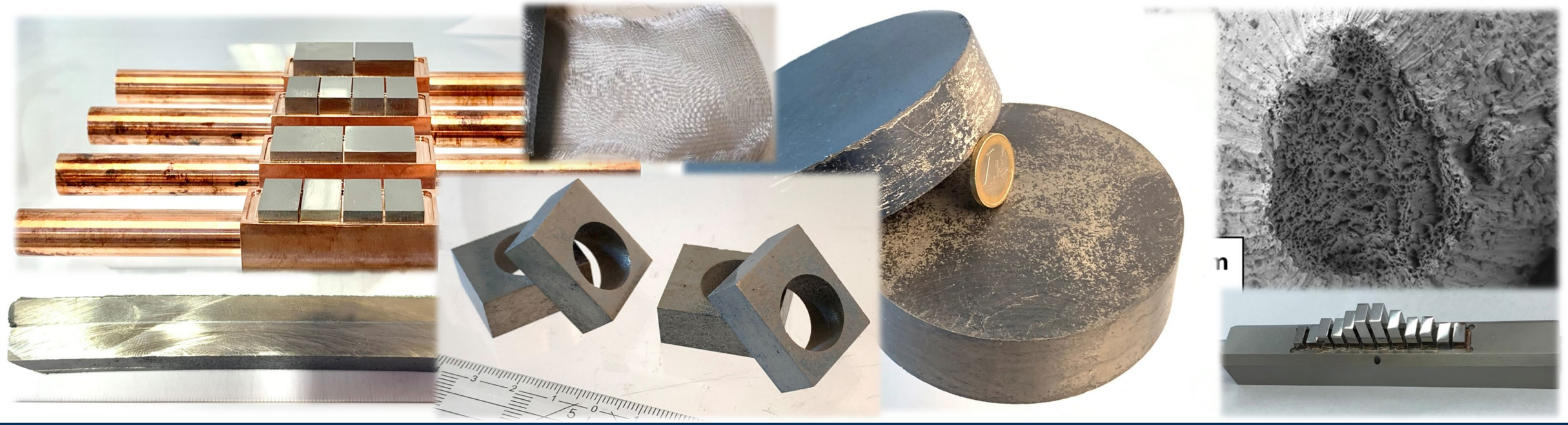


Plasma-facing components based on tungsten fiber-reinforced tungsten composites

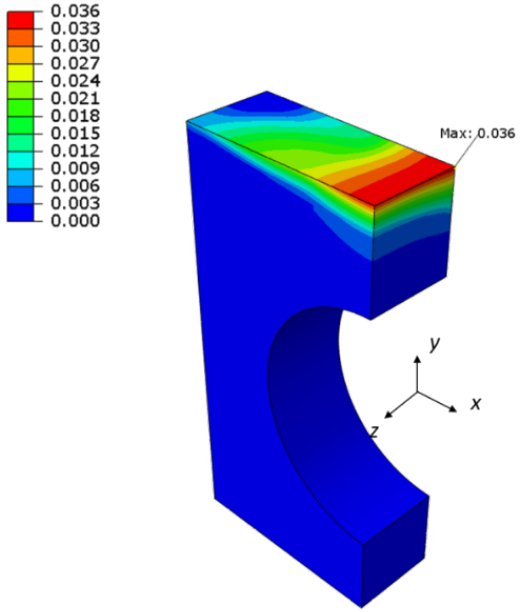
2022.11.09 I Yiran Mao, Jan Coenen, Alexis Terra, Rui Shu, Xiaoyue Tan, Chao Liu, Till Hoeschen, Johann Riesch, Yucheng Wu, Christoph Broeckmann, Rudolf Neu, Christian Linsmeier

EUROfusion

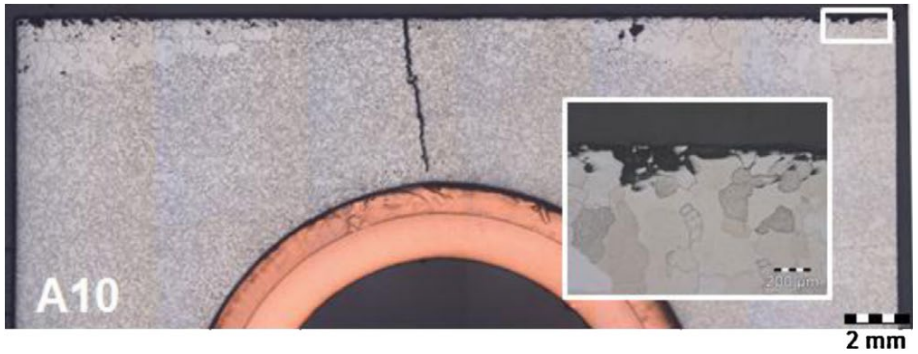
This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Crack formation for tungsten armor

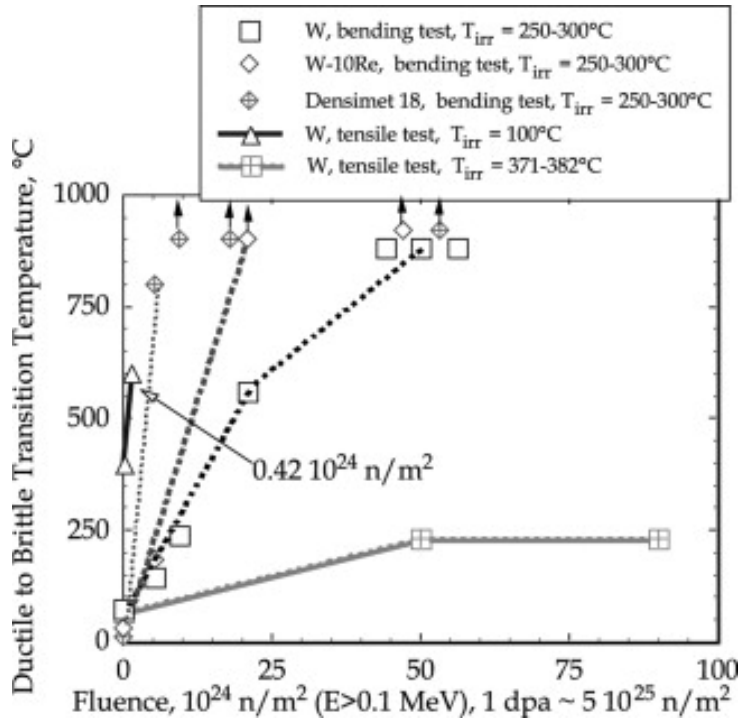
- Intrinsic brittleness of tungsten material
- Thermal heat load at the divertor: thermal stress and thermal fatigue



Accumulated equivalent plastic strain field in the tungsten armor block after the 5th HHF load cycle at 20 MW/m^2. -M.Li 2015.



G. Pintsuk et al. / Fusion Engineering and Design 88 (2013) 1858–1861 1861

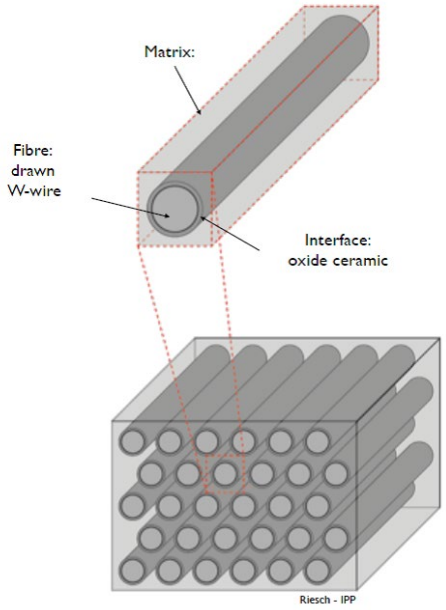


H Bolt, et al; Journal of Nuclear Materials, Volumes 307–311, Part 1, 2002, Pages 43-52

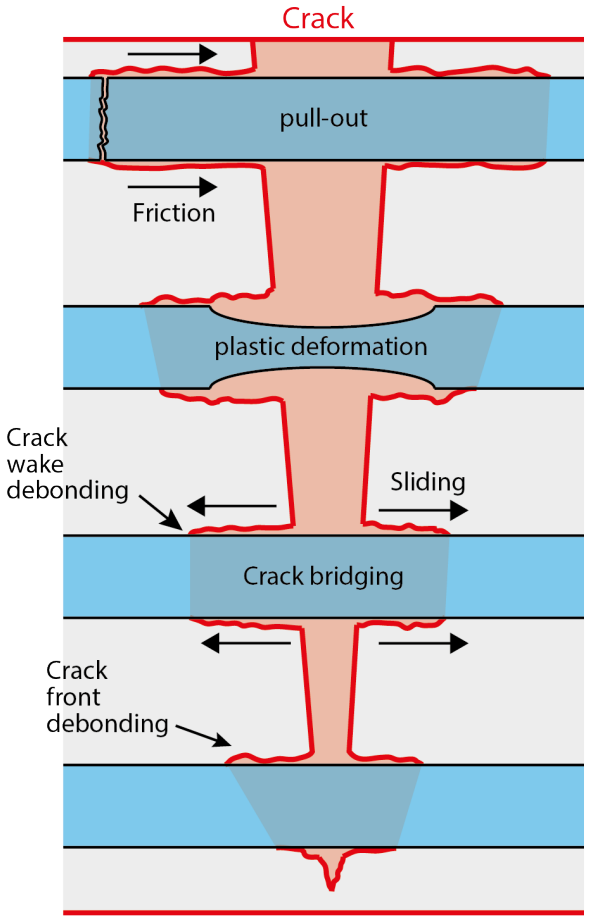
Neutron embrittlement

A damage resilient material is required

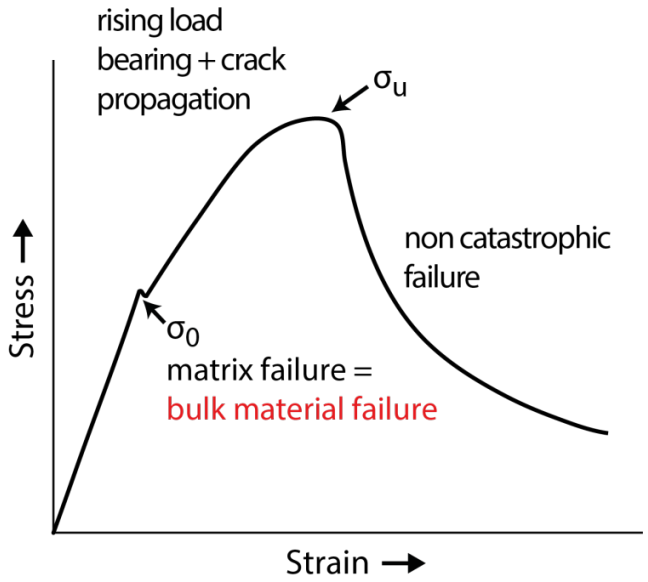
Solution: Tungsten fiber reinforced tungsten composites



Tungsten fiber-reinforced tungsten (W_f/W)

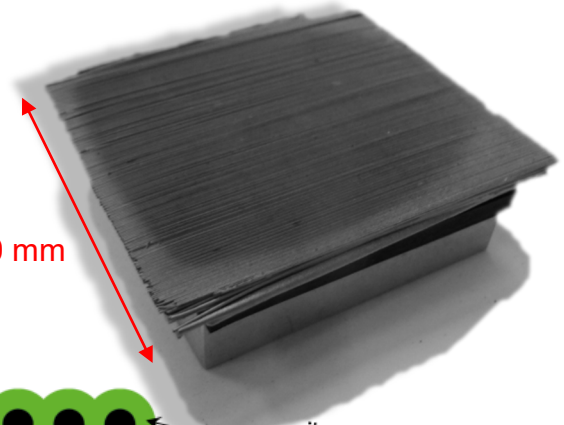


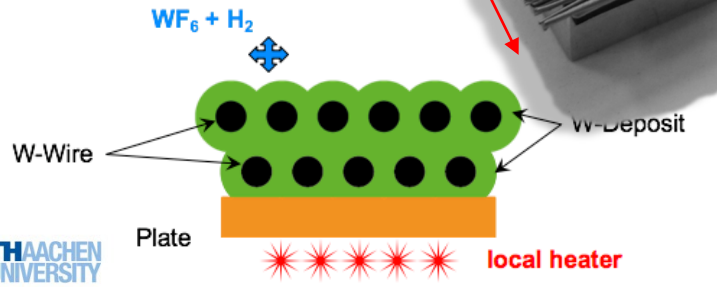
Pseudo ductile behavior

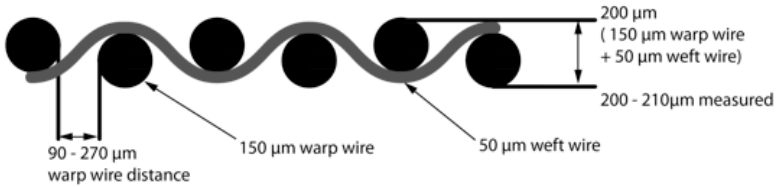


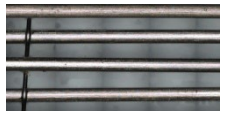
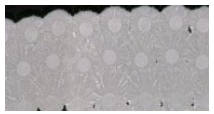
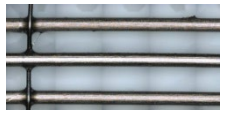
W_f/W

Available Samples

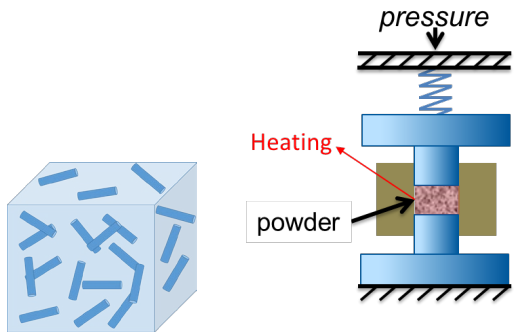




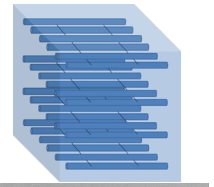


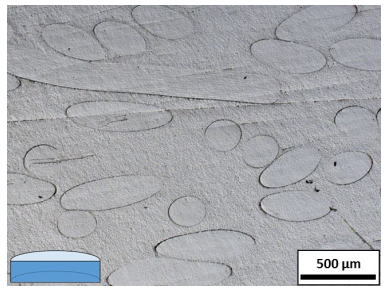
	Wire spacing:		Density:	Theoretical V_f:
	158 ± 17 µm		96.5%	18.6 %
	204 ± 19 µm		99.3 %	14.4 %
	271 ± 10 µm		99.7%	10.1 %

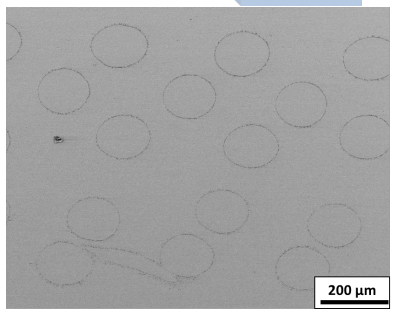
Coenen, J & others
Advanced materials for a damage resilient divertor concept for DEMO: Powder-metallurgical tungsten-fibre reinforced tungsten *Fusion Engineering and Design, Elsevier BV*, **2017**, *124*, 964-968

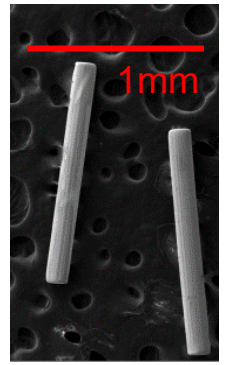


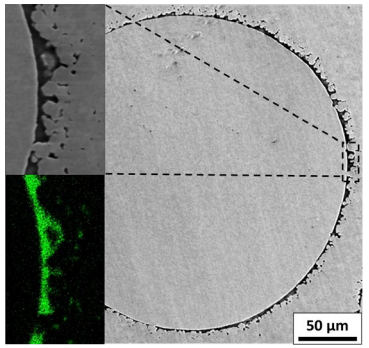
FAST

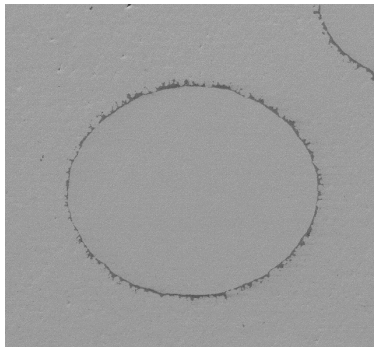








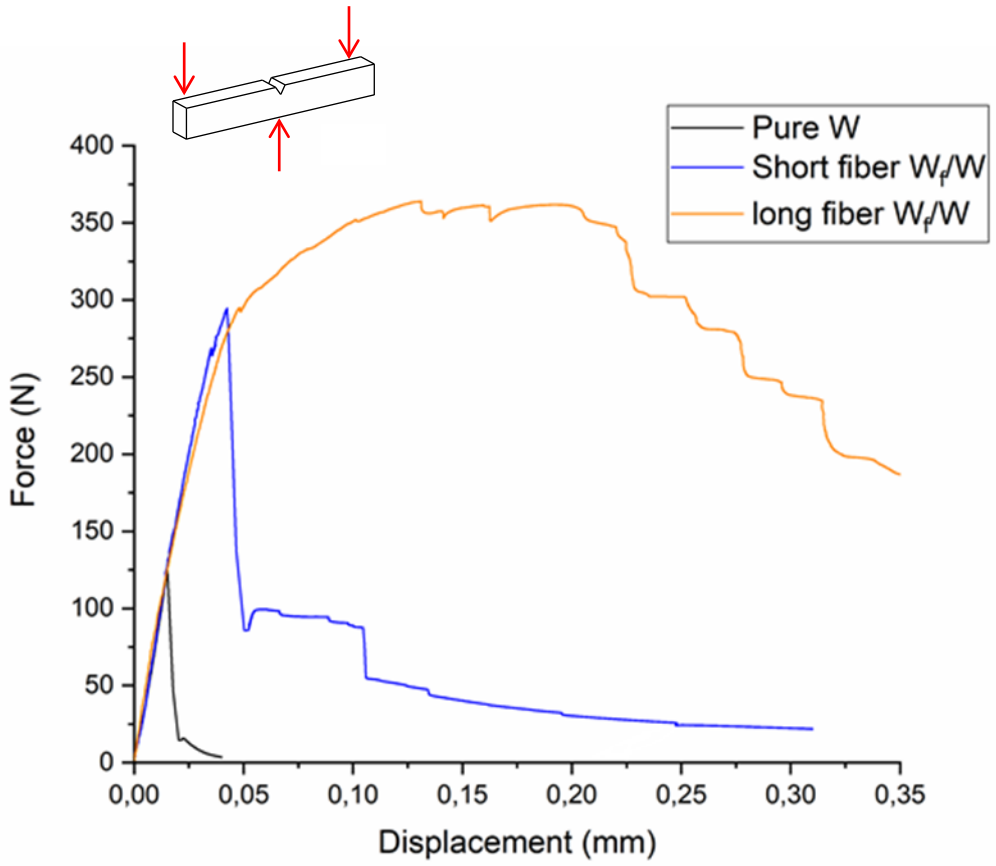


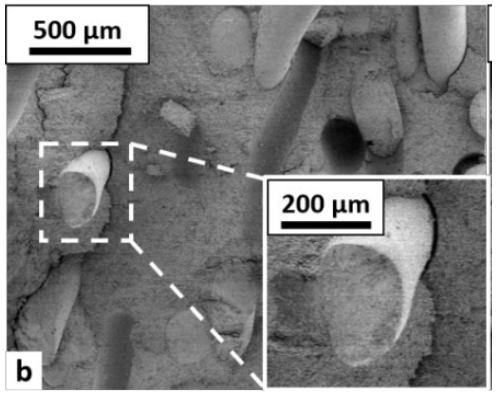


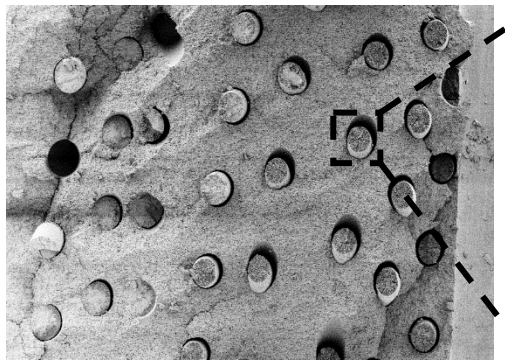
Gietl, H.; v Müller, A.; Coenen, J.W.; Decius, M.; Ewert, D.; Höschen, T.; Huber, P.; Milwich, M.; Riesch, J. & Neu, R. Textile preforms for tungsten fibre-reinforced composites *Journal of Composite Materials, SAGE Publications*, **2018**, *52*, 002199831877114

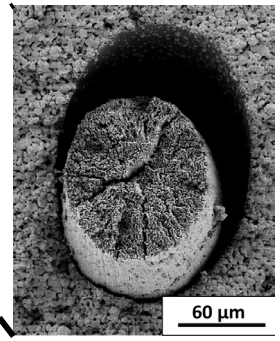
JÜLICH Forschungszentrum

Mechanical properties of PM W_f/W





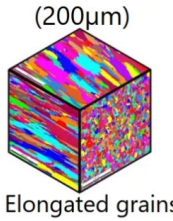


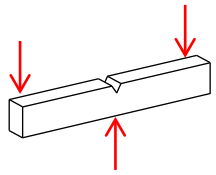


Samples	Fracture energy density (kJ/m^2)	Fracture toughness, K_q($MPa\ m^{0.5}$)
Pure tungsten	0.1±0.0	5.5±0.0
Short fiber W_f/W	1.9±0,7	25.5±7.8
Long fiber W_f/W	11.6±3.1	67.6±15.0

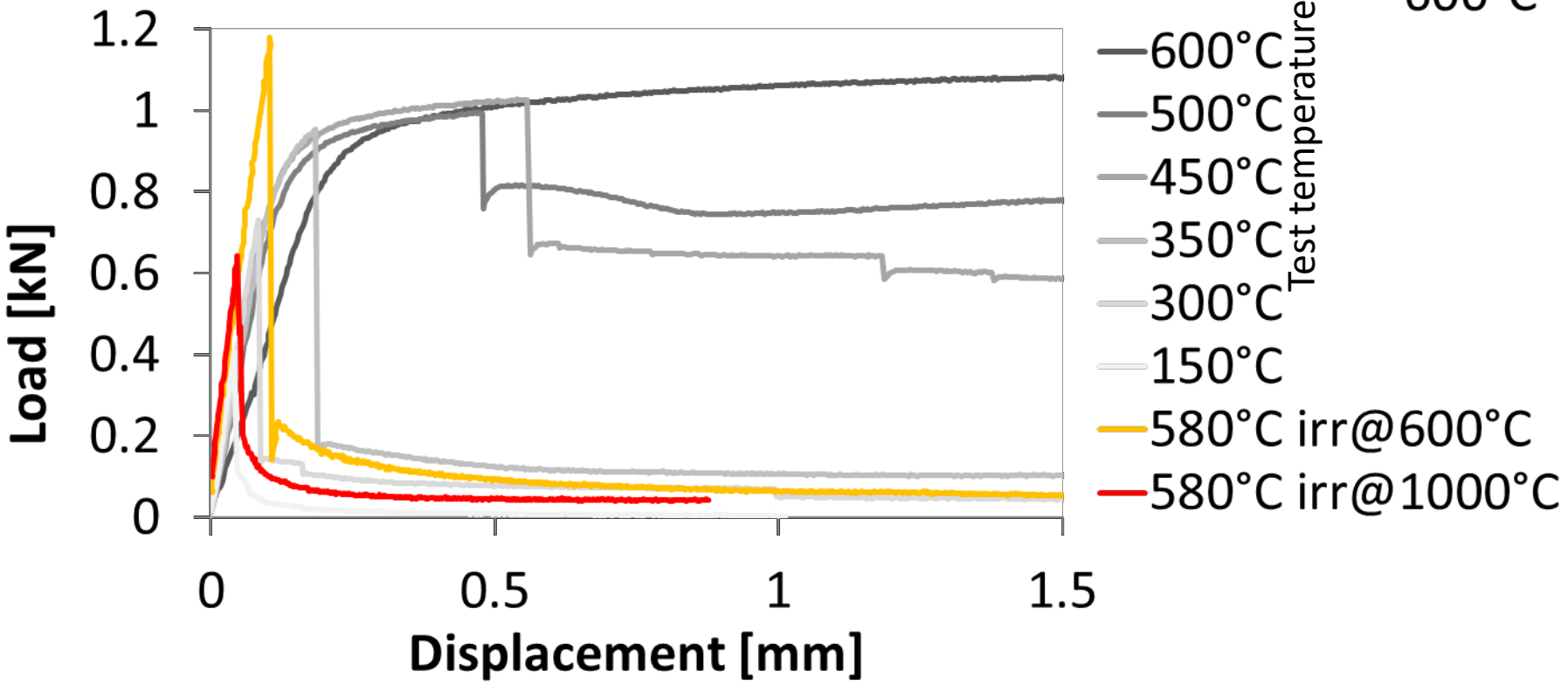
Long fiber W_f/W show more promising mechanical properties compared to short fiber W_f/W

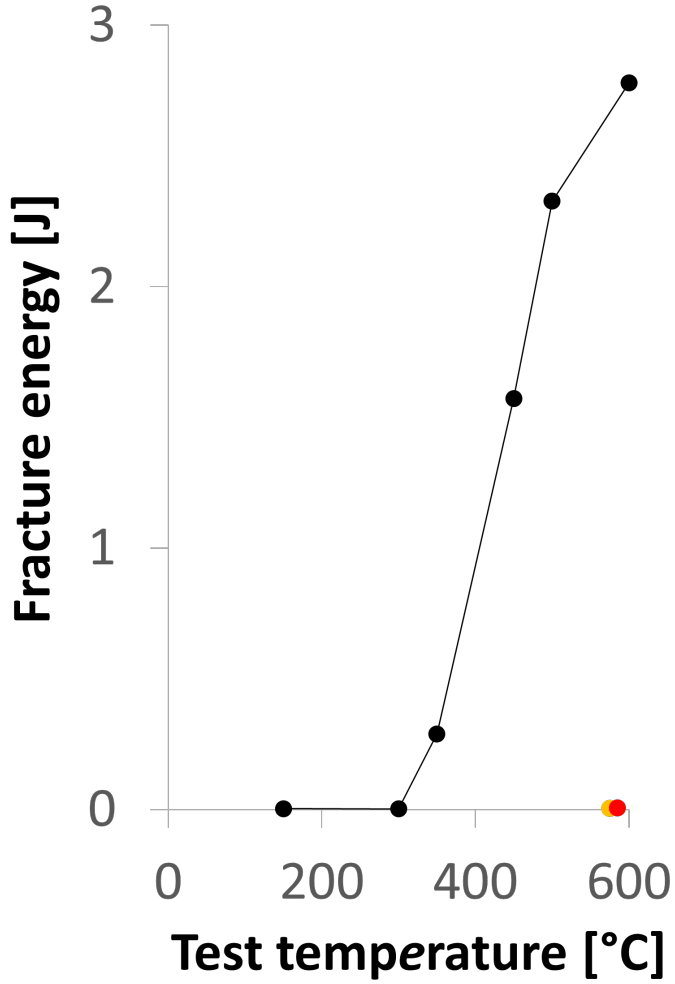
‘ITER grade’ W irradiation





The **irradiated (1 dpa)** material becomes brittle at 580°C

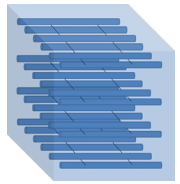


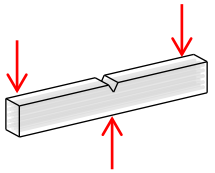


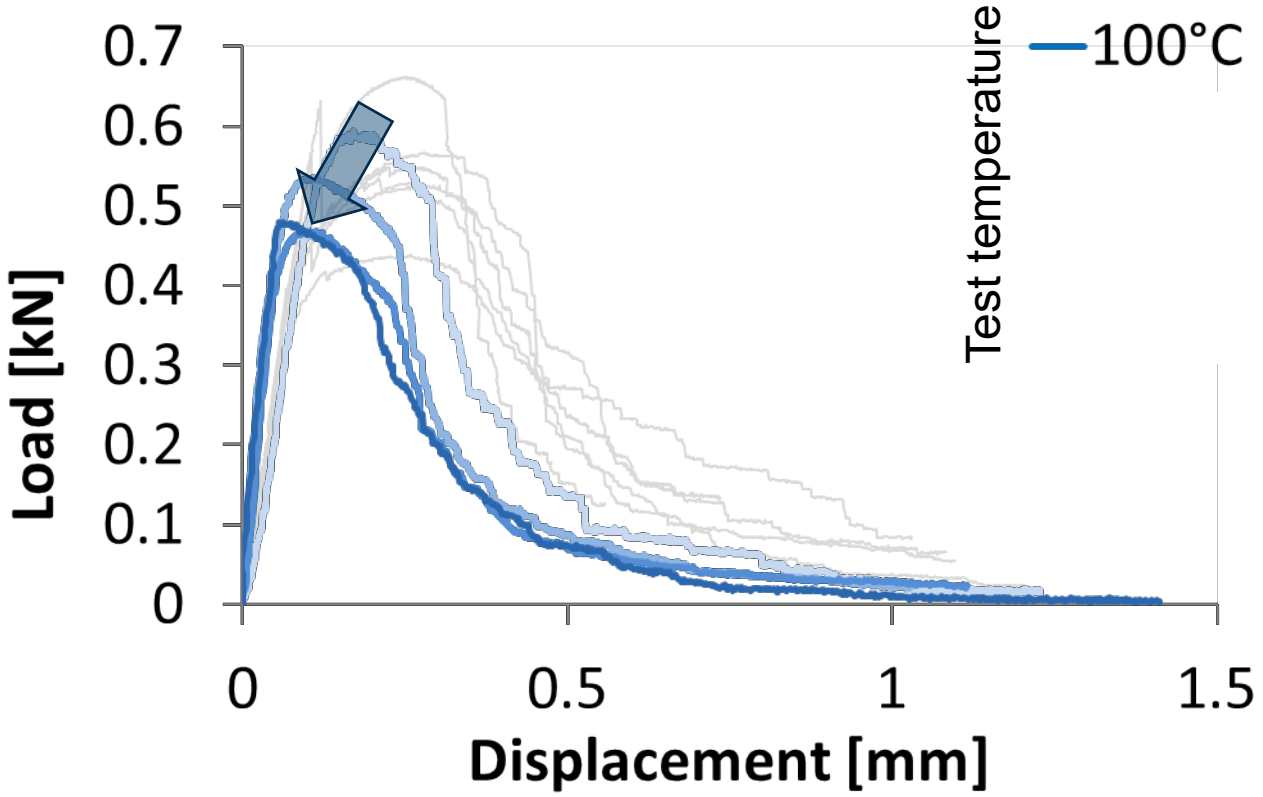
-Till Höschen and A. Zinovev et.al., ICFRM-20

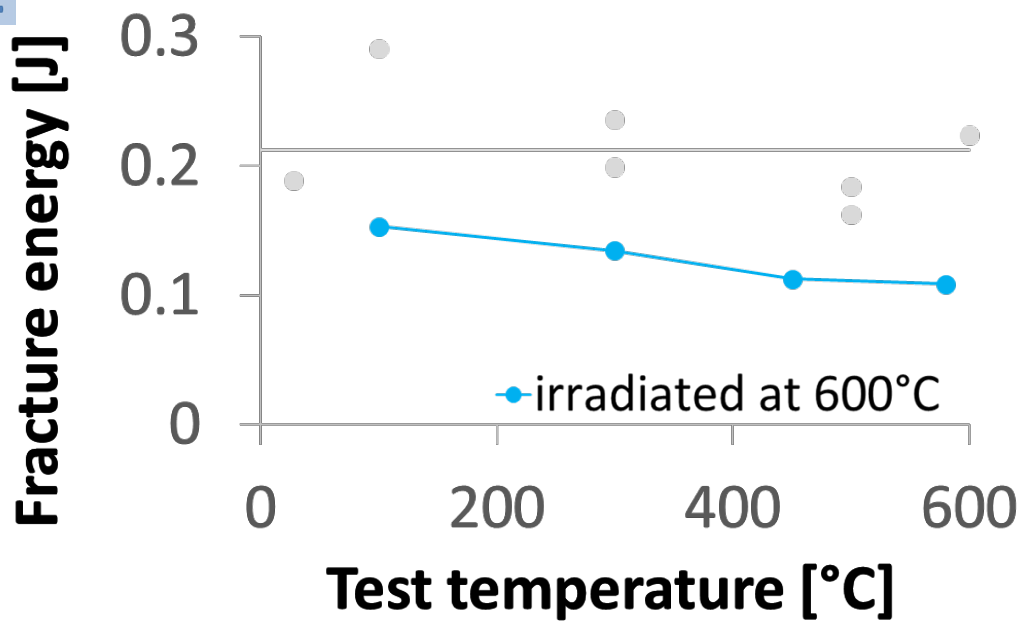
W_f/W Long Fibre Material

Samples irradiated at 600°C to 0.7 – 0.8 dpa









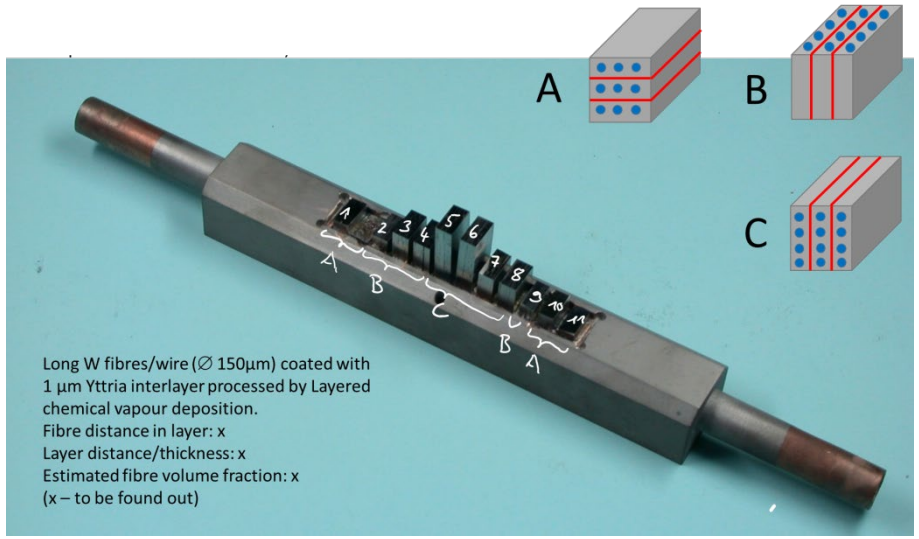
- Decreasing maximum load with rising temperature
- Reduced fracture energy

No brittle failure, even at low test temperature

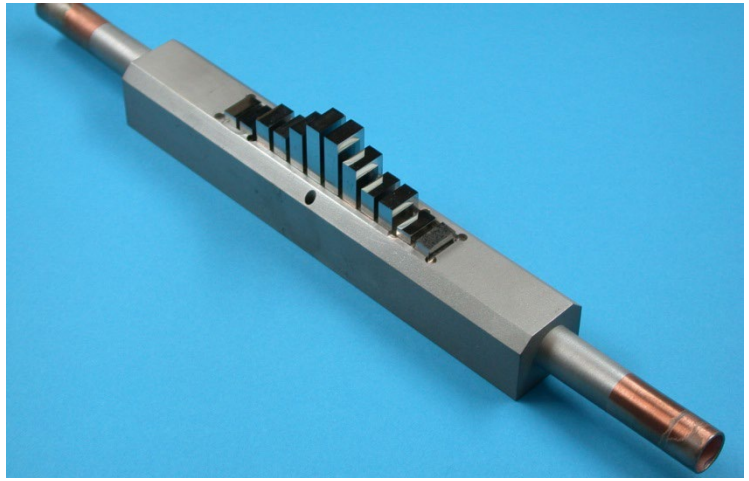
-Till Höschen and A. Zinovev et.al., ICFRM-20

Status of HHF tests of W_f/W mock-ups

Sample arrangement of CVD-W_f/W B1 mock-up



PM-W_f/W B1 mock-up, one type of samples
(short W fibre s)



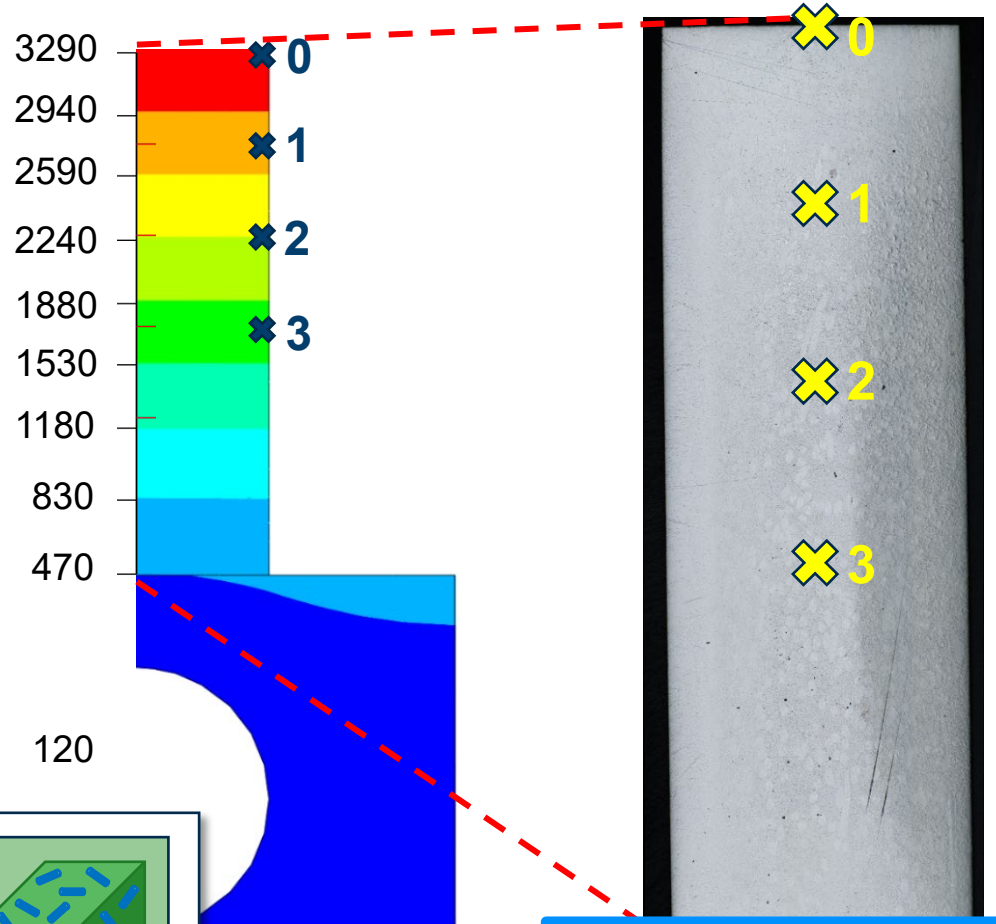
3 tests performed in 2020 -2022

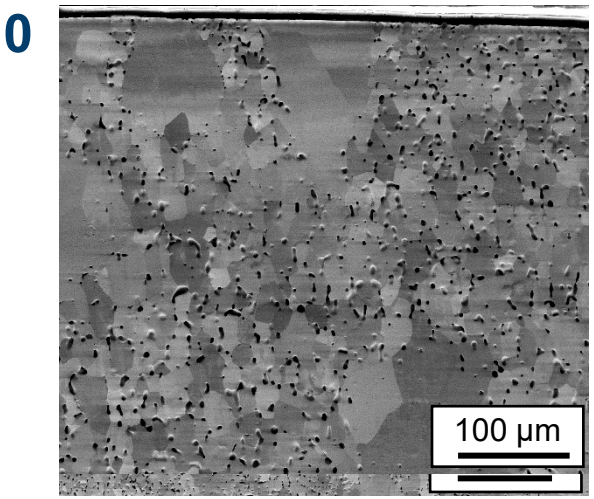
After successful cycling tests, 100 × 10 MW/m² → increase of heat flux

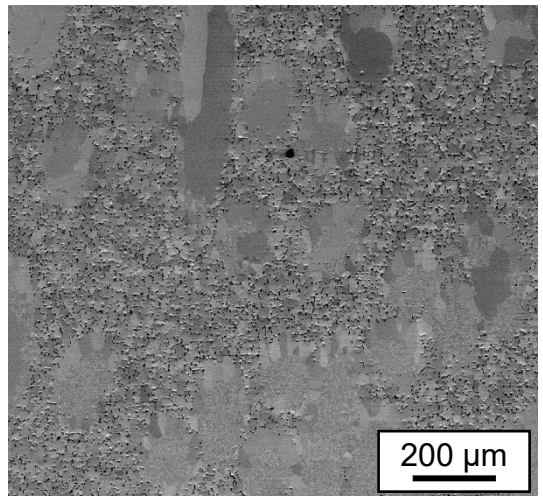
First step: screening tests of both mock-ups up to 15MW/m², resulting in max T_{surf} 2900 °C

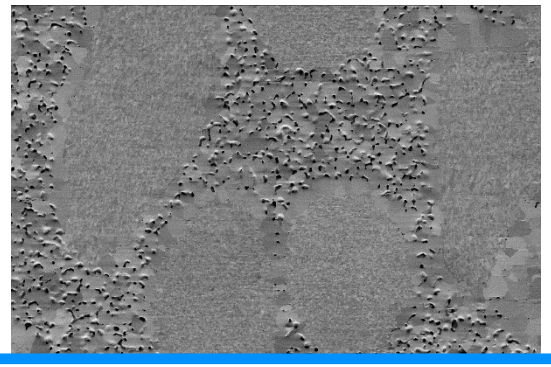
- Second step: 100 cycles at 15 MW/m²
  - Both mock-ups survived in good conditions, no unexpected defects however partial delamination of individual CVD-W_f/W occurred.
- 3nd test campaign performed at 20MW/m² without major defects

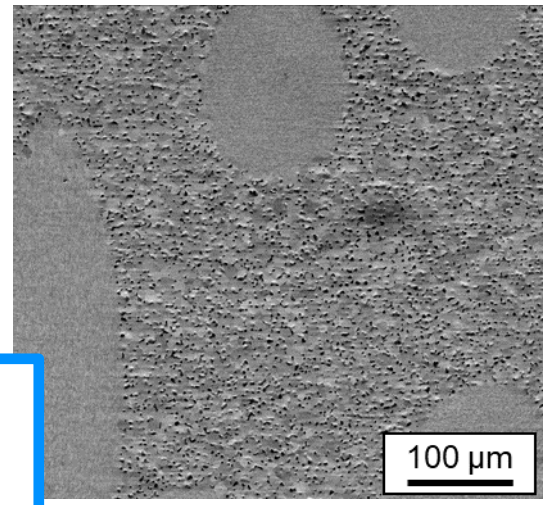
Recrytalization behavior after 15 MW/m2





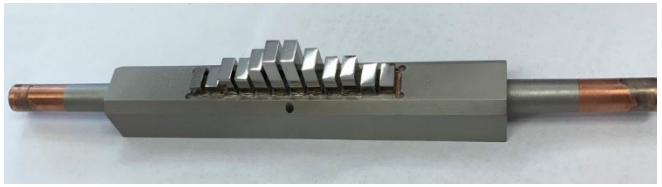


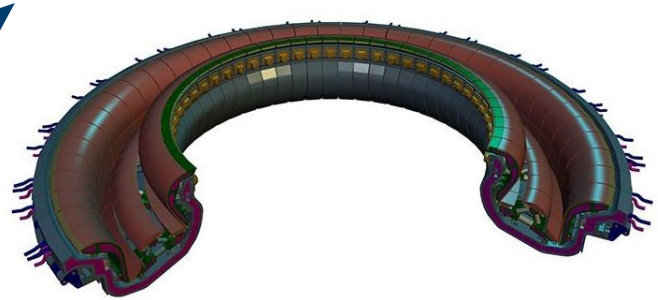




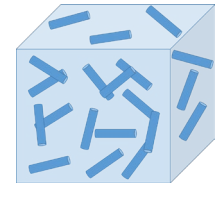
K-doped-Fiber recrystallisation & grain growth starts at >1800°C;
full recrystallisation only >2300°C (“standard” W **≈1300°C**)

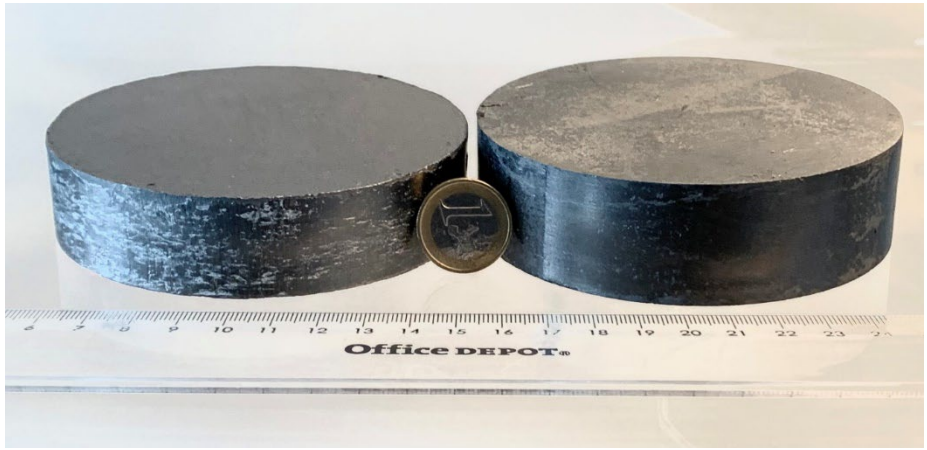
Production upscaling



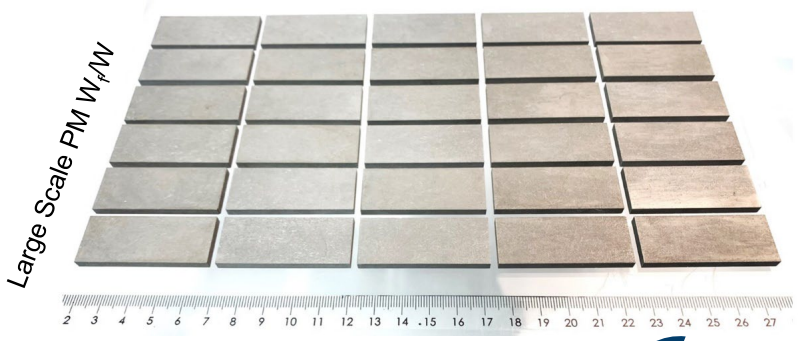


Large scale FAST/SPS facility in HFUT, sample geometry up to 300 mm in diameter





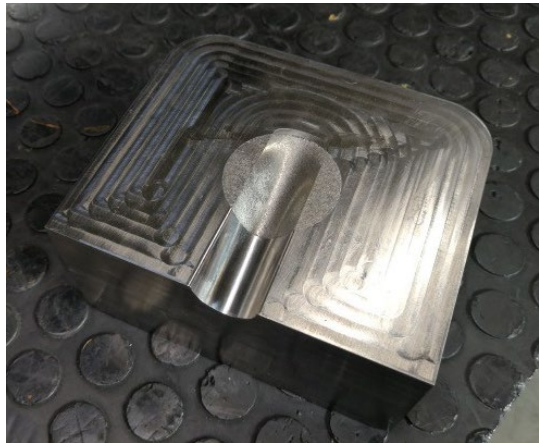
- Sample with a dimension of 105 mm x 30(25) mm has been produced



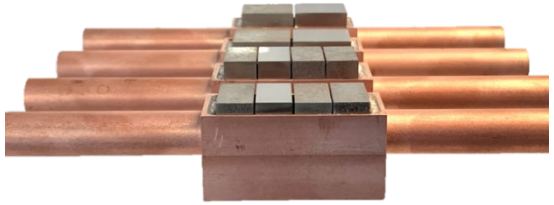
Application projects

Fusion Technology Transfer Action

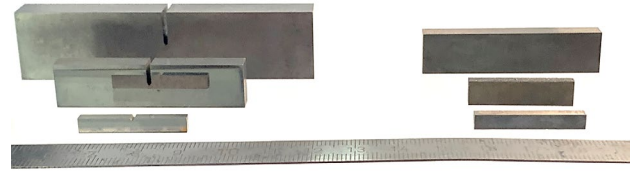
Breuckmann



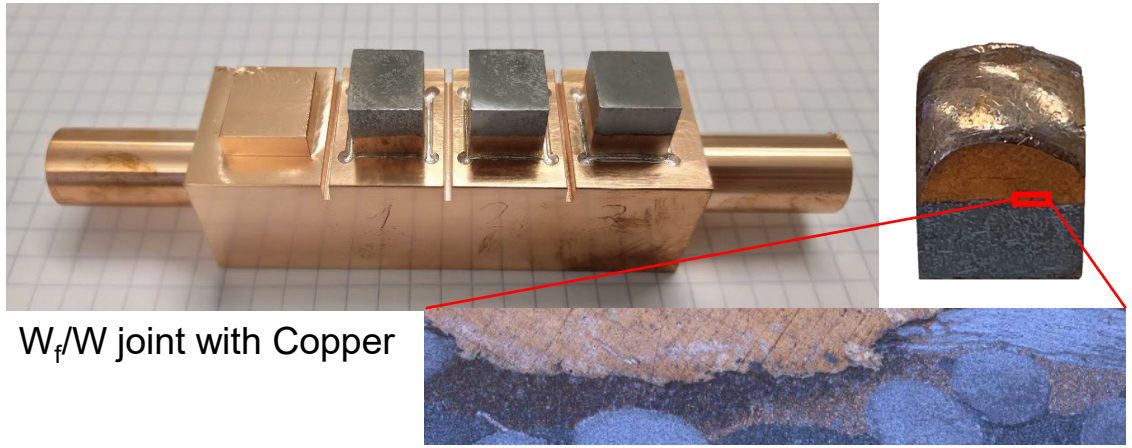
W_f/W Application in foundry industry
Melt guiding part



Flat tiles design with W_f/W
Up to 23 x 28 x 8 mm

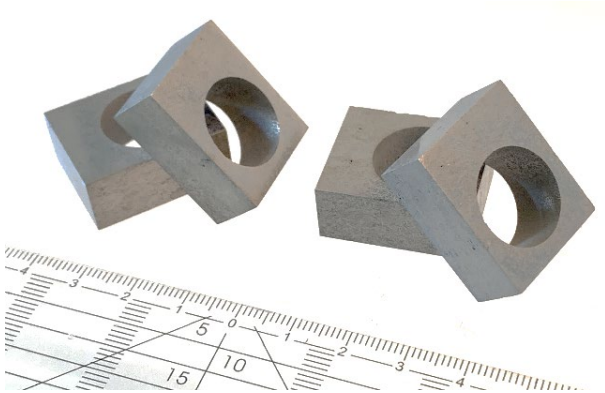


Mechanical tests with different size
up to 84 mm x 20 mm x 10 mm



W_f/W joint with Copper

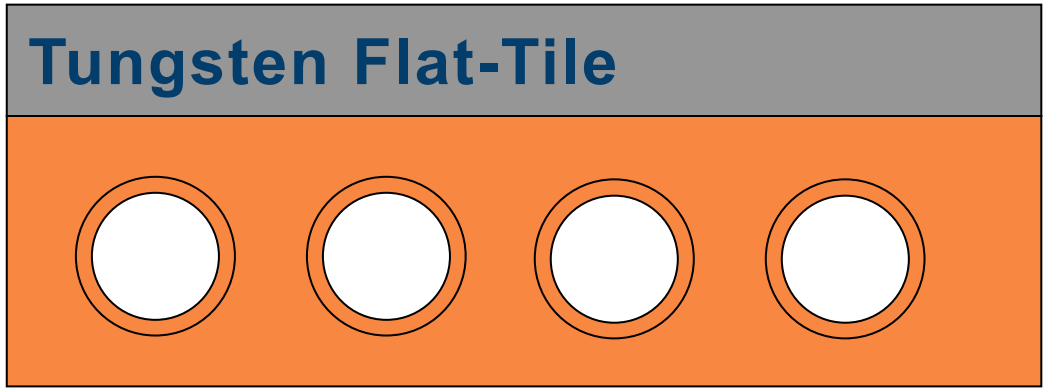
Cu infiltration into the porous matrix



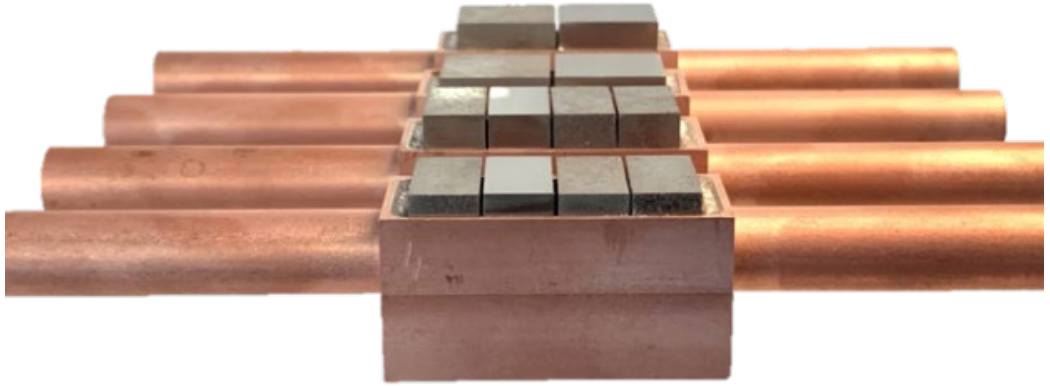
W_f/W monoblocks, 28 x 12 x 23 mm

Component design, W_f/W joint
with steel via V
20 mm to 105 mm in diameter

Finding an Application of the Material



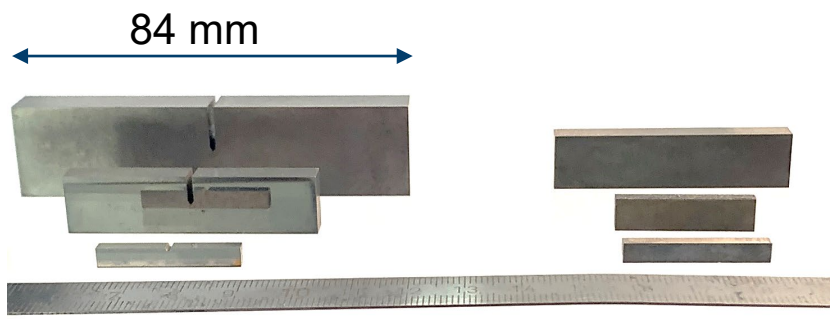
- For a Composite Material a dedicated way of solving problems or adding operational space can be found

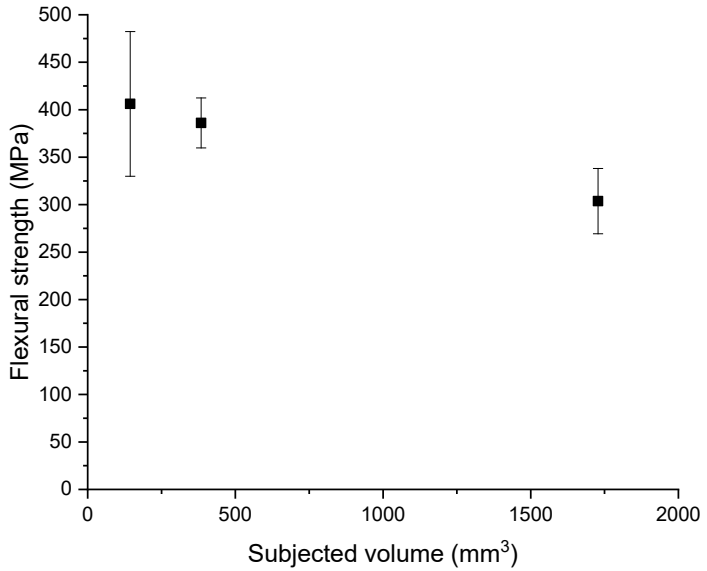


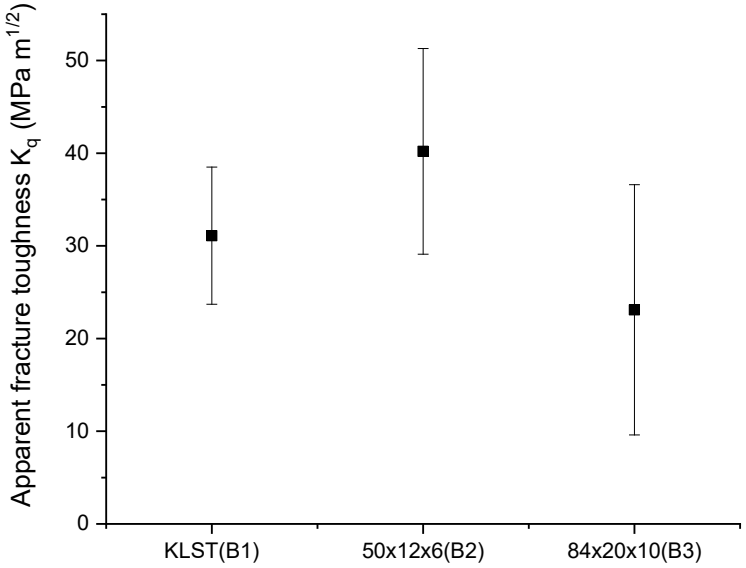
Flat tiles design with W_f/W
Up to 23x28x8 mm

- ➢ E.g allow operating W_f/W above 1500 ºC
- ➢ Stable properties during irradiation
- ➢ **No need for monoblock – joining W_f/W & W_f/Cu**

Mechanical tests upscaling and size effect







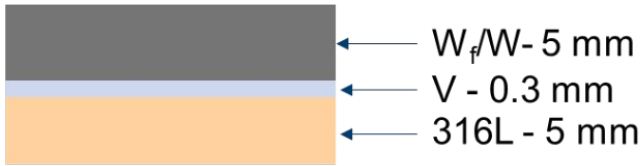
- Flexural strength and fracture toughness has been measured based on different sample dimension
- Flexural strength decreases slightly with increasing sample dimension corresponding to the sample size effect
- Fracture toughness of the sample decreases when the sample dimension more close to the plain strain condition. The overall value stays at a high level compared to pure W.

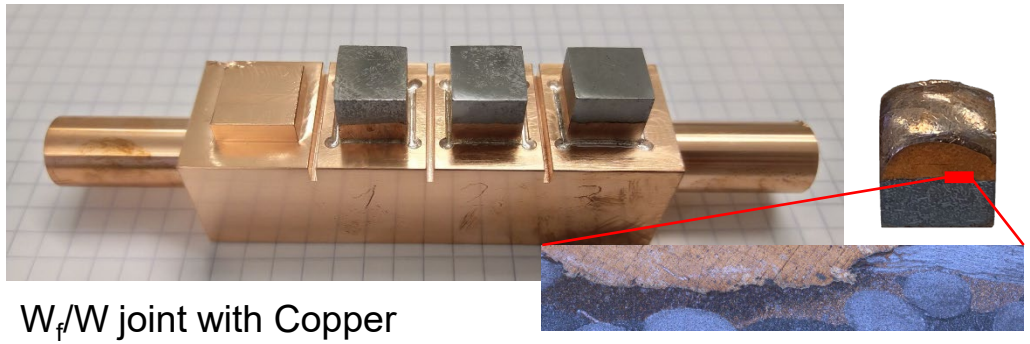
Building a component

Joining of W_f/W with steel

- For Advanced Divertors with high heat fluxes > 20MW/m^2 at elevated temperatures (> 1500ºC) likely new options could be helpful
- W_f/W with long fibres based on PM seems an option that with the right joint technology can be readily available

Production	Parameters
Temperature	850°C
Pressure	30MPa
Holding time	15min
Heating rate	25K/min
Cooling rate	5K/min





W_f/W joint with Copper

Cu infiltration into the porous matrix

HHF Tests & Component Design as well as irradition tests are needed

tokamak energy
a faster way to fusion

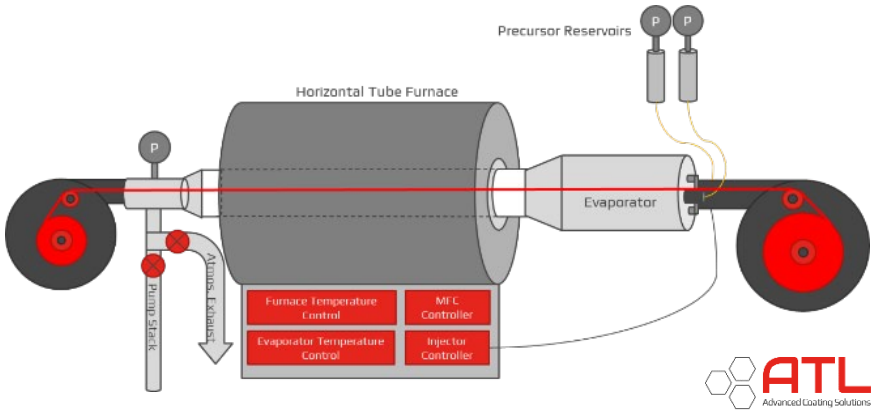
JÜLICH
Forschungszentrum

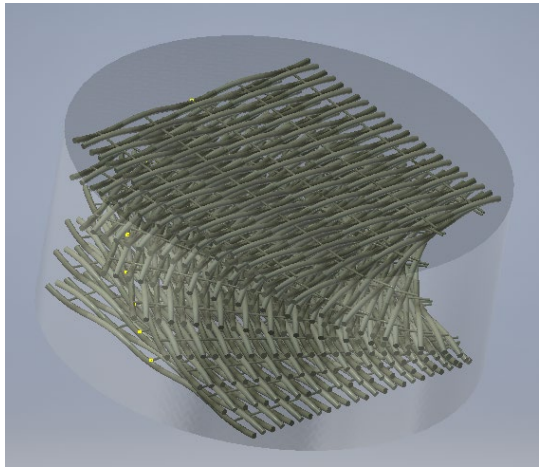
Development outlook

-upscaling of the long fiber W_f/W

Typical samples

105 mm x 10-30 mm, 1.5-4.5 kg





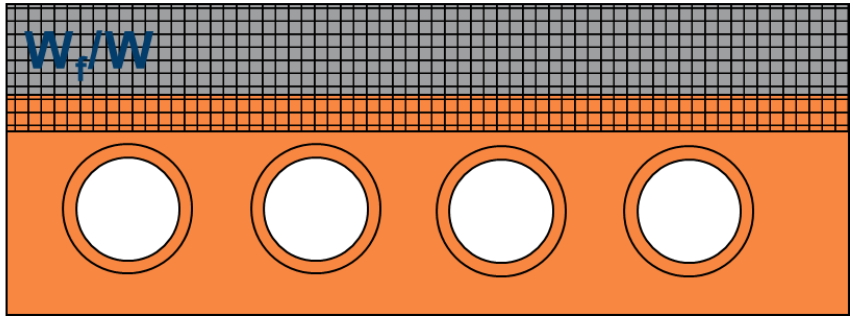
105 x20 mm

Summary

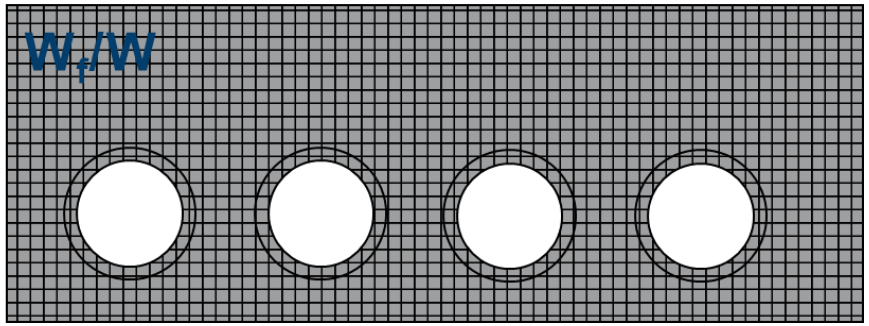
Integrated approaches aiming for extra engineering design space

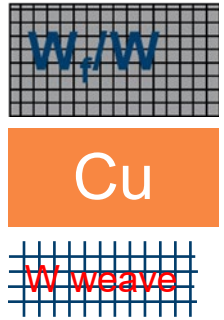
- Production of W_f/W can be realized by powder metallurgy process
- Recently we have realized the production of long fiber W_f/W via powder metallurgy process combining the advantages of easy production and advanced mechanical properties
- Various characterization methods have been done for W_f/W showing the improved damage resilience, at higher temperature and also after neutron irradiation.
- Production upscaling has been made for short fiber W_f/W by powder metallurgy process and multiple projects running based on the large scale samples.
- New concepts have been raised based on current materials.

Advanced concept - What goes beyond what exists



CVI produced W_f/W with infiltrated copper Coolant (missing proof of principle)





Complet Wf/W based component CVI / PM With 3D weaves – needs development