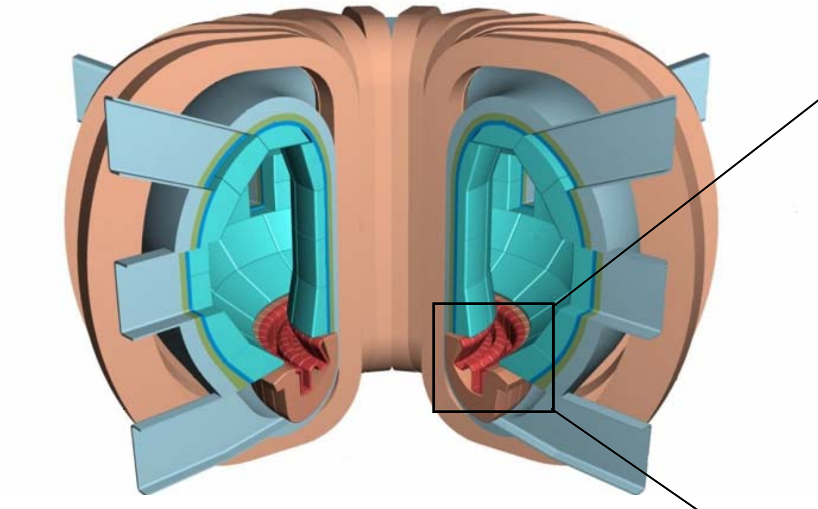
Heat flux tests of SiC-fibre reinforced Cu matrix composite

V. Paffenholz, H. Greuner, B. Böswirth, A. Brendel
IPP

Outline

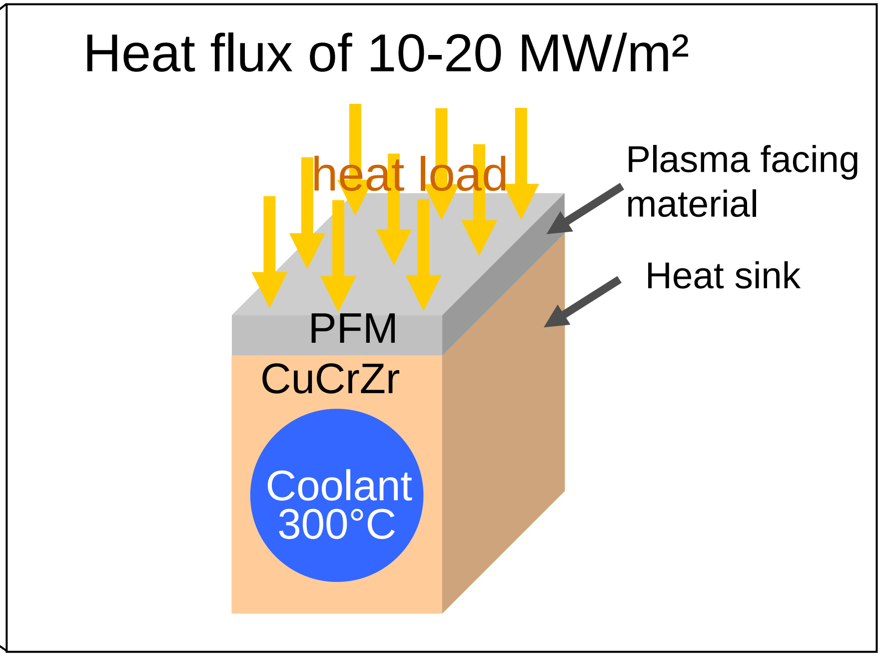
1. Requirements for DEMO
2. Processing of metal matrix composites (MMC)
3. GLADIS - High heat flux tests
4. Microscopy analyses after heat flux tests
4. Summary



DEMO: demonstration reactor

- Deuterium-tritium plasma
- Fusion power 2000 MW

DEMO - Divertor



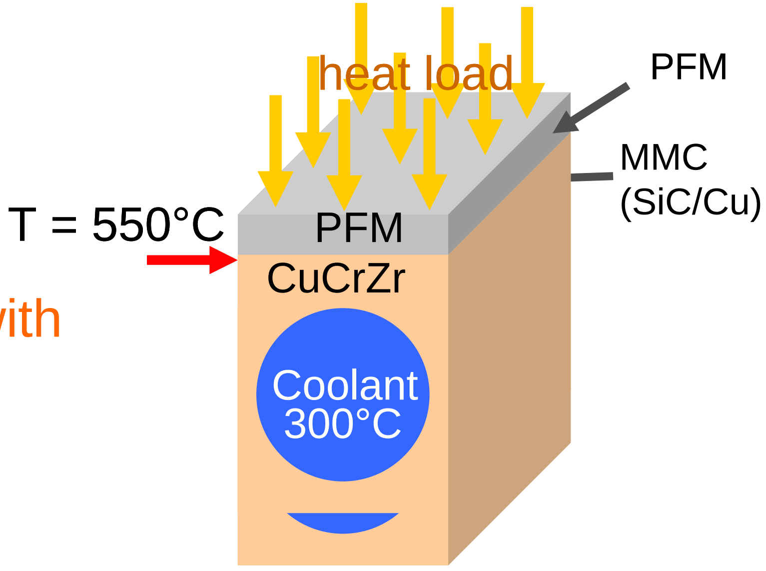
Deuterium + Tritium = Helium + Neutron + 17.59 MeV

Aim: High cooling temperature necessary for a high efficiency of future fusion reactors

- High temperature (~550°C) at the interface plasma facing material/heat sink
- Stresses due to different CTEs & temperature gradient at the W/CuCrZr interface

⇒ MMC interlayer – Cu matrix reinforced with SiC fibres

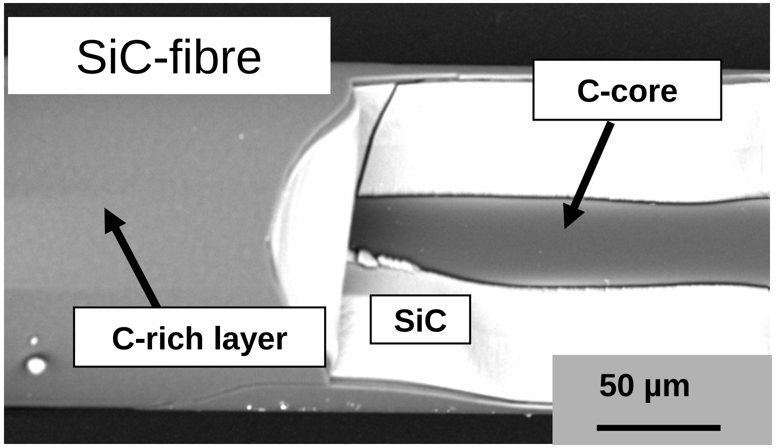
- High thermal conductivity ~200 W/mK
- Sufficient mechanical strength



Processing of MMCs - flat-tile mock-up

Fibre

- SCS6-Fibre (Specialty Materials)
  ø = 140 µm
- Carbon rich layer at the surface for protection during handling
- Developed for titanium matrix

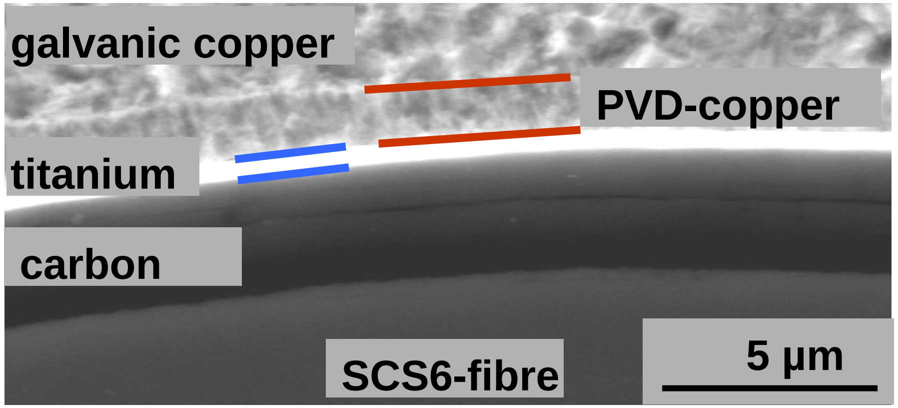


Deposition – fibre matrix interface

Magnetron sputtering:

- Ti interlayer (~ 200 nm)
- Cu layer for protection (~500 nm)

➔ Good bonding fibre/matrix

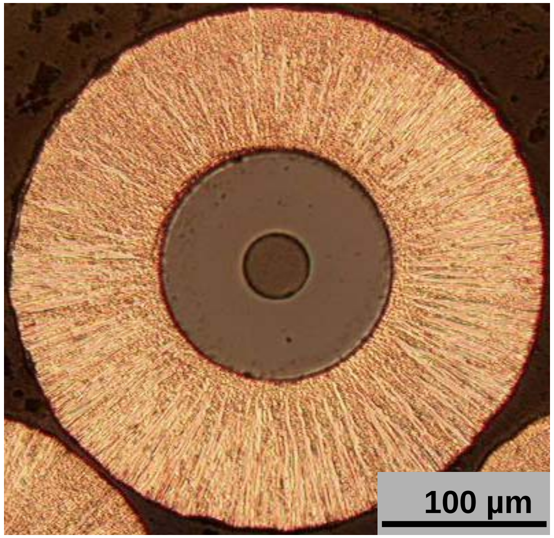


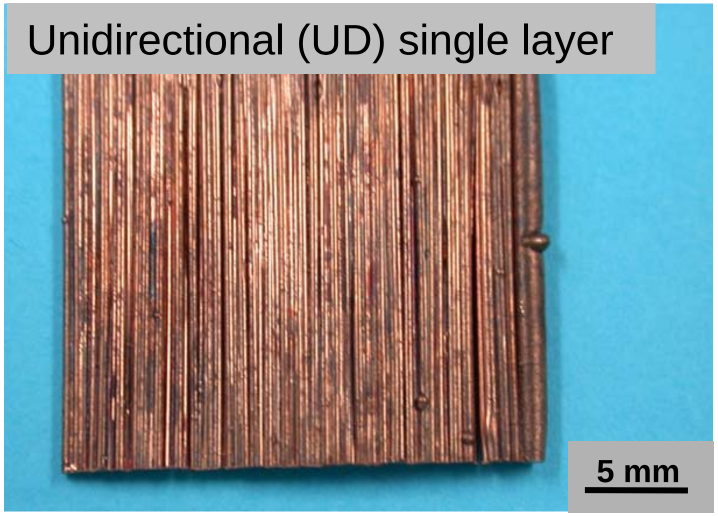
Processing of MMCs - flat-tile mock-up

Deposition – Cu matrix

Electroplating of copper as matrix material in a $CuSO_4$ bath at RT by two subsequent processes

1. Fibres coated for 1 h
2. Coated single fibres were fixed on a frame, coated for 10 h





Deposition time defines Cu thickness ➔ fibre volume fraction

EUROMAT 2009, 9.09.09 © Verena Paffenholz

Processing of MMCs - flat-tile mock-up

Heat treatment

- Outgassing of hydrogen, slow heating rate of 20 K/h up to 550°C
- Reduction of porosity
- TiC formation

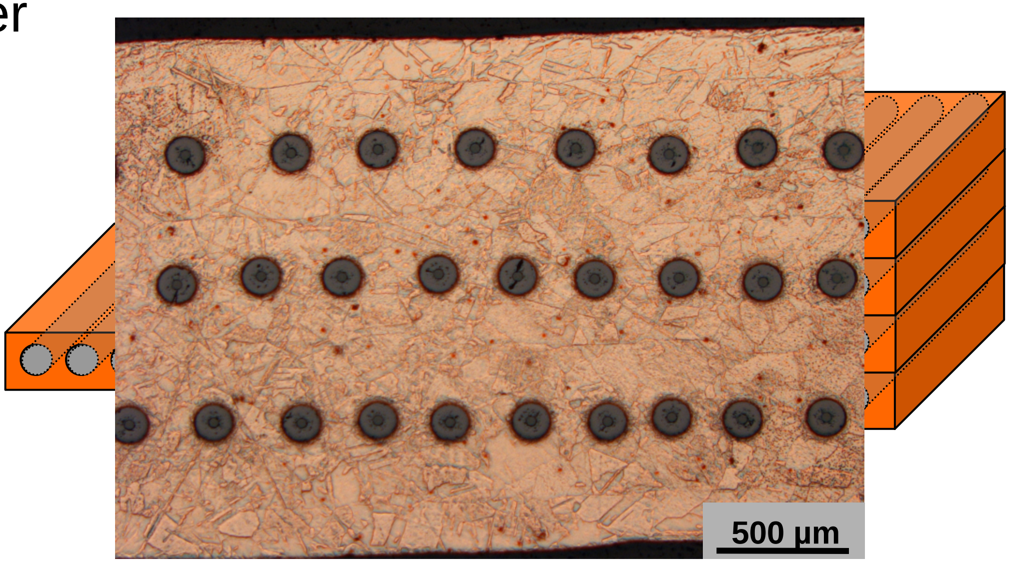
Etching of UD single layers

Etching agent: phosphoric acid, nitric acid, acetic acid

➔ Removing of oxide layer

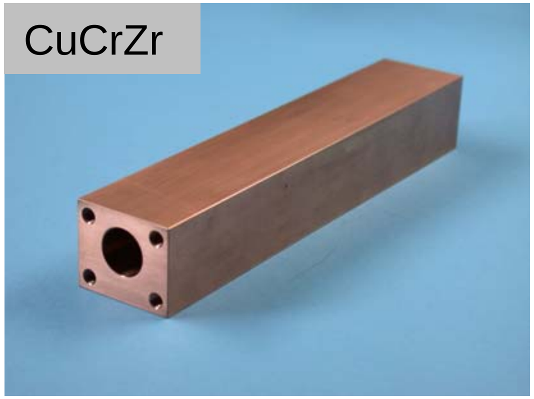
Consolidation

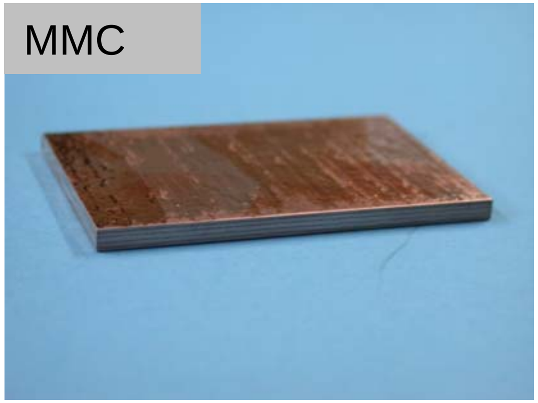
Vacuum hot pressing to form the MMC specimens
650°C (1h), ~40 MPa

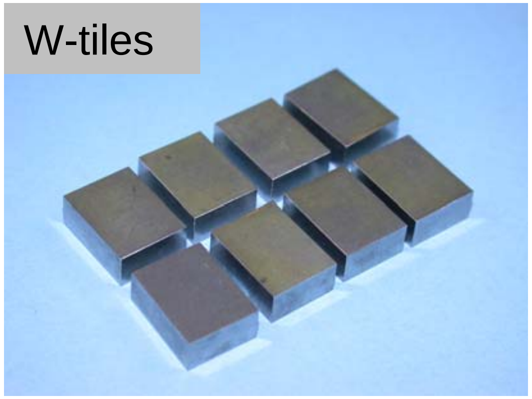


Processing of MMCs - flat-tile mock-up

Components of flat-tile mock-up



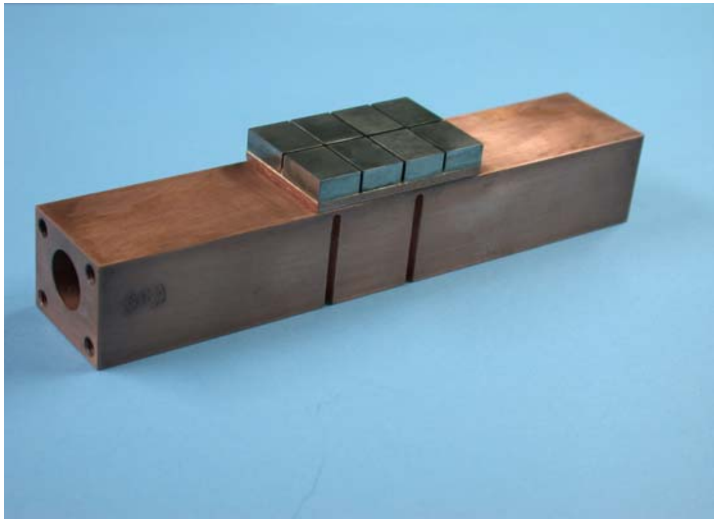




- CuCrZr
- MMC interlayer (41,5x27x2,5mm³)
  v_f ~14%, 4 or 5 layers, 0°/0°
- 8 W tiles (10x13x5mm³)

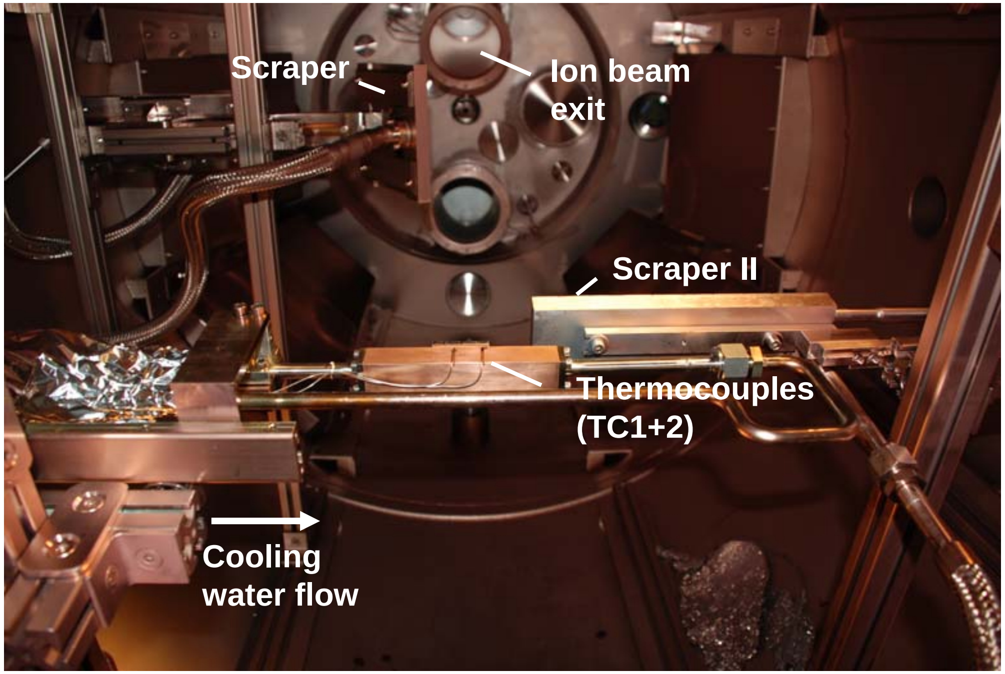
➔ Brazing of components
by Ansaldo (Gemco brazing foil)

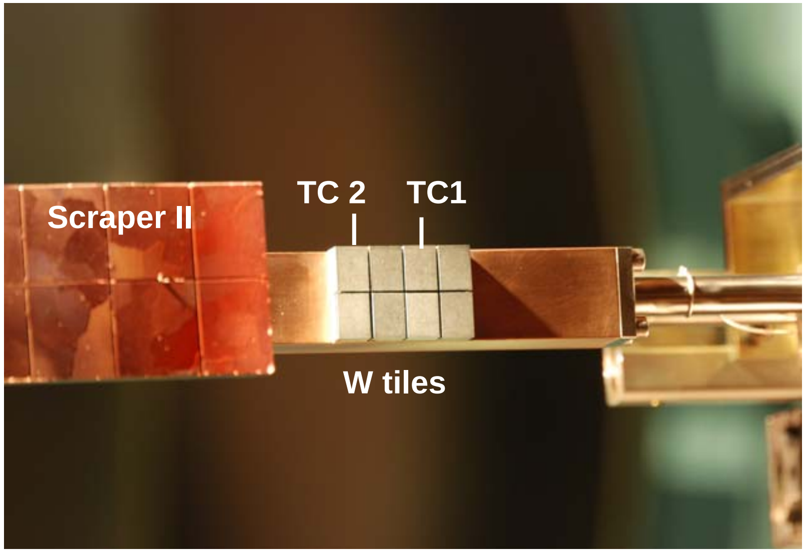
➔ 3 flat-tile mock-ups



GLADIS – high heat flux tests

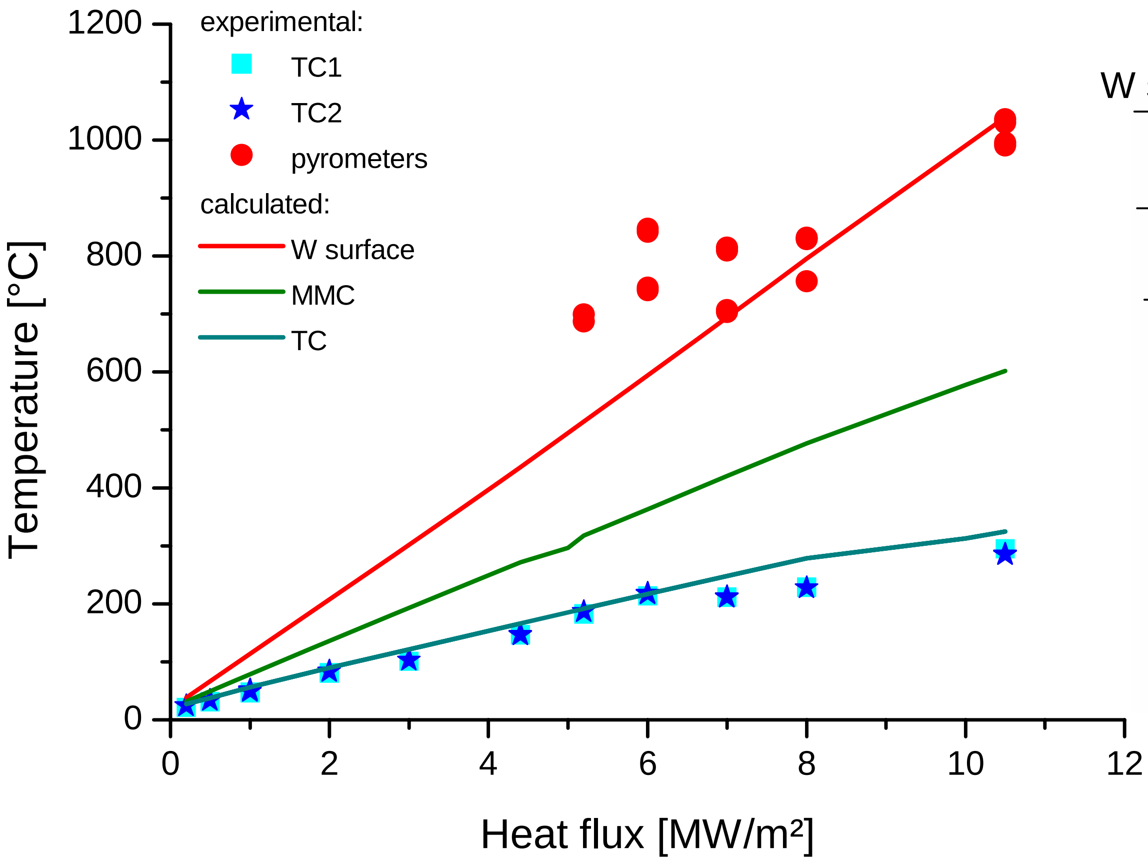
GLADIS vacuum chamber

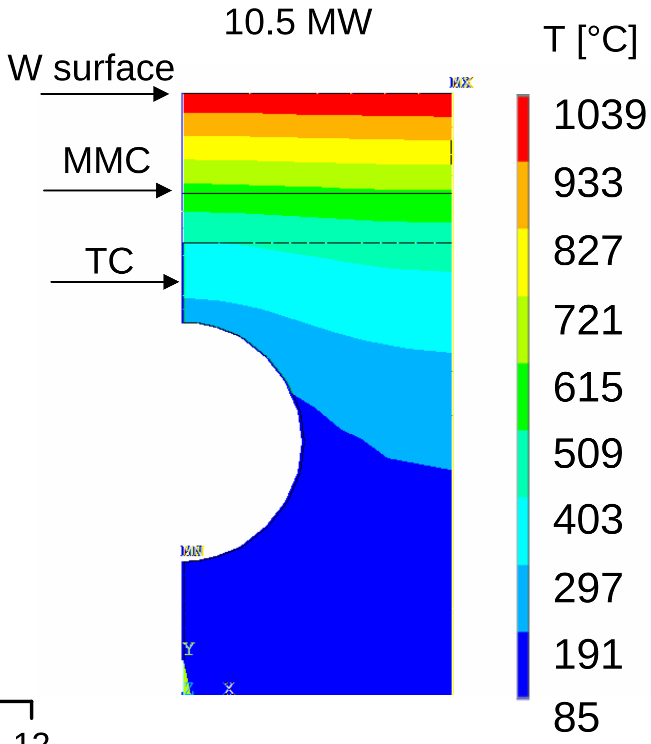




T-analysis:	IR camera, pyrometers, thermocouples, CCD video camera	
Heat flux tests:	screening:	0.2 MW/m² - 10.5 MW/m² (30 s)
	cycling:	10.5 MW/m² (20-80 cycles, 20 s)

GLADIS – high heat flux tests

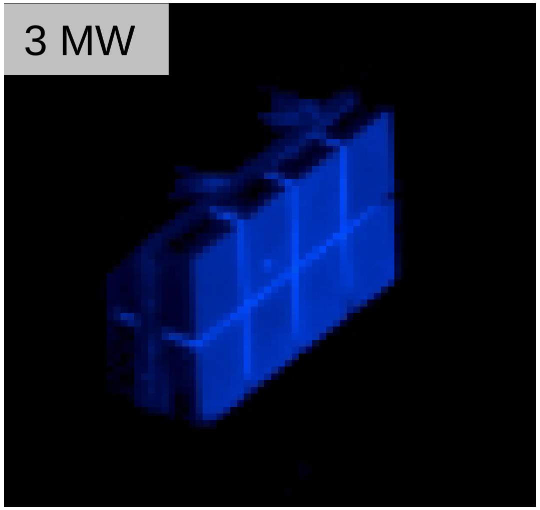


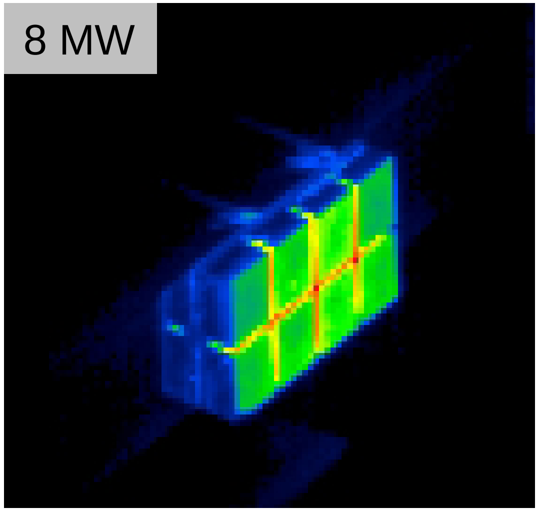


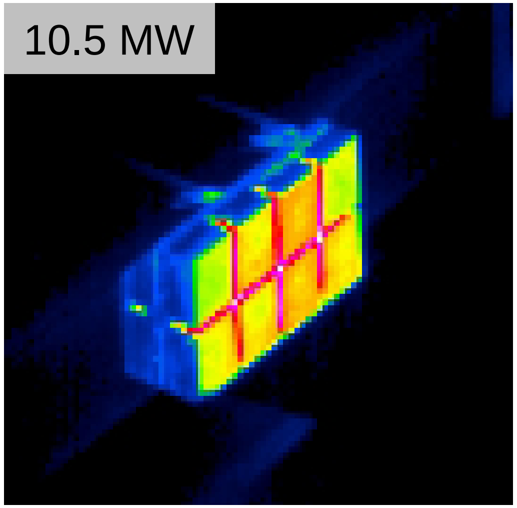
- Good correlation between measured and calculated temperatures
- Highest temperature at the W-surface at the edge of mock-up

GLADIS – high heat flux tests

Screening mock-up 4: 0.2 – 10.5 MW/m²

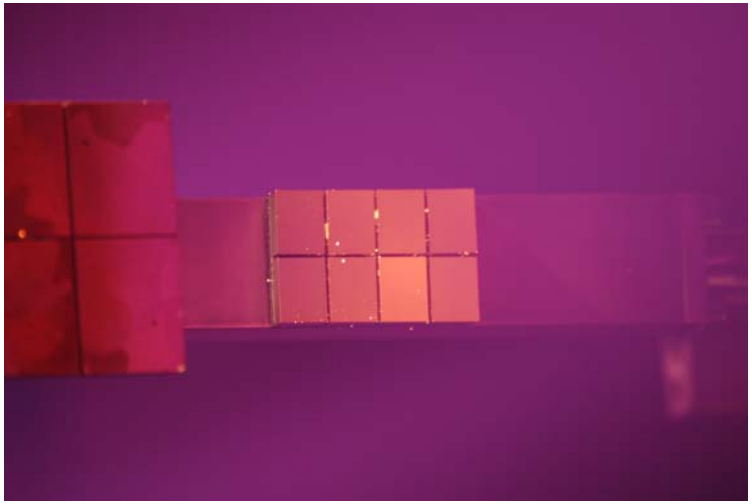






- Uniform temperature distribution
- Fast and uniform cooling of W-tiles
- No overheating of W-tiles
- No damage visible

➔ Sufficient heat transport at 10.5 MW/m²



GLADIS – high heat flux tests

Cycling mock-up 4: 10.5 MW/m², 40 cycles + 40 cycles (6 W-tiles)

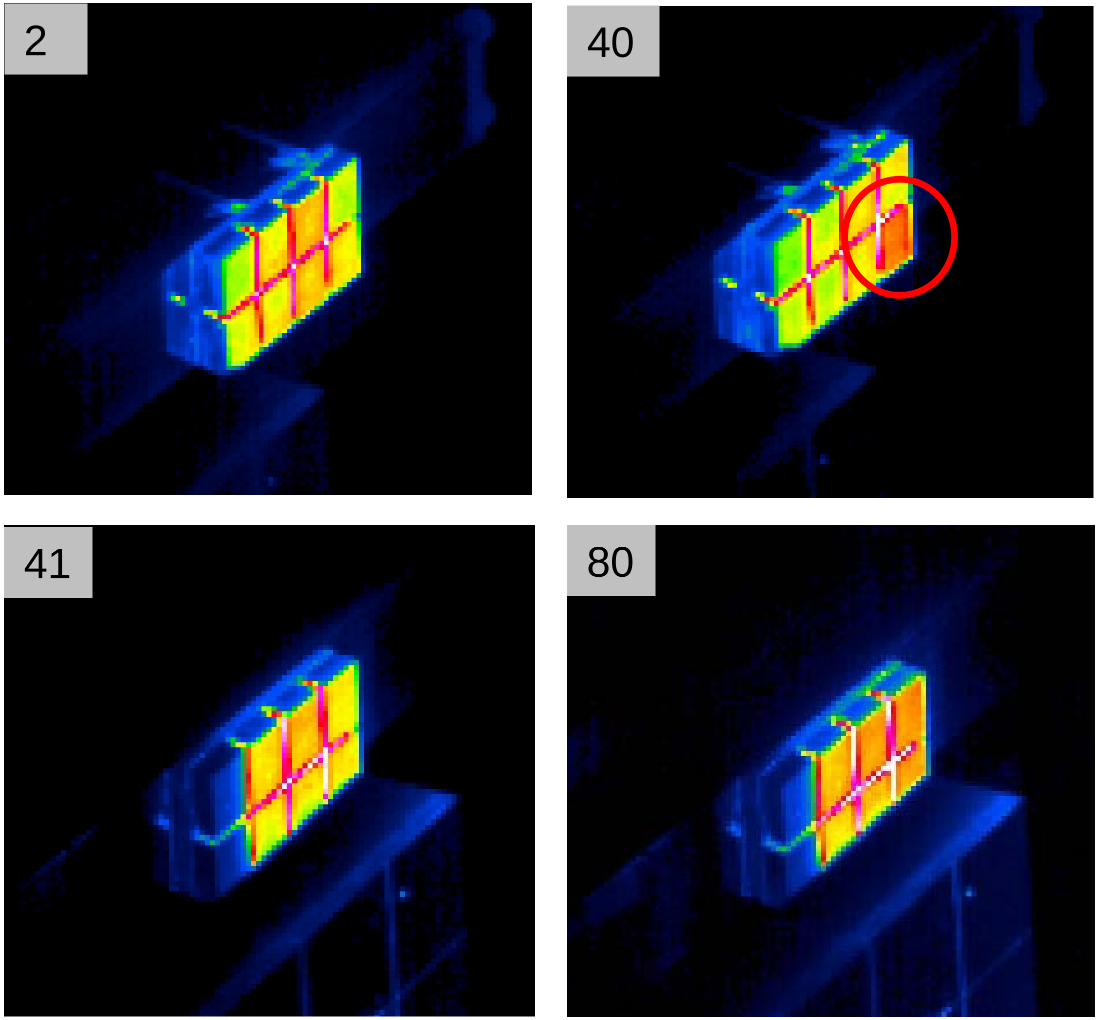
Overheating of one W-tile

➔ Stop after 40 cycles

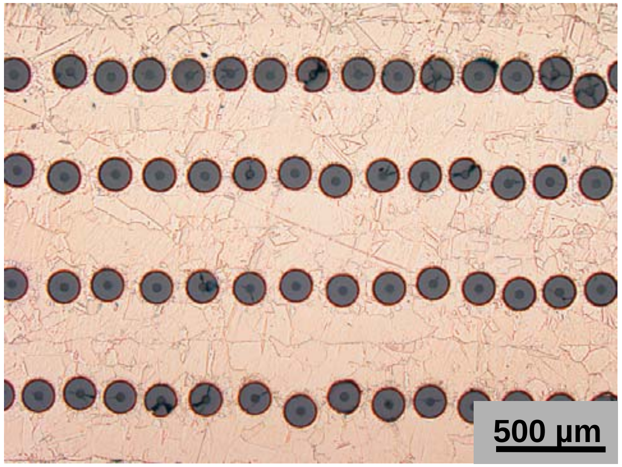
➔ Covering of damaged W-tile

Continuous temperature rise at surface of W-tiles

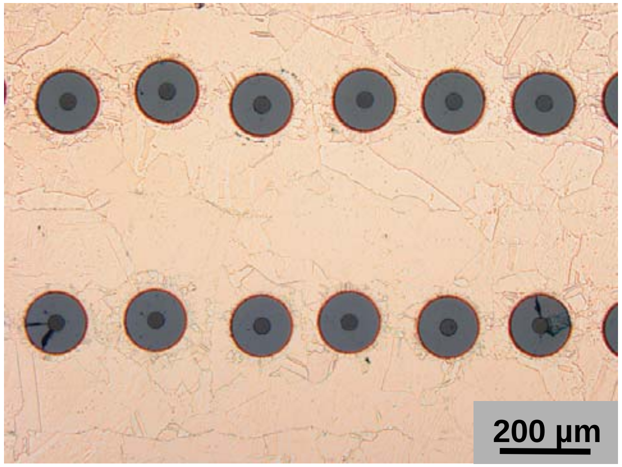
➔ Stop after 80 cycles

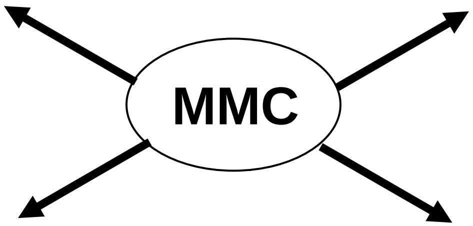


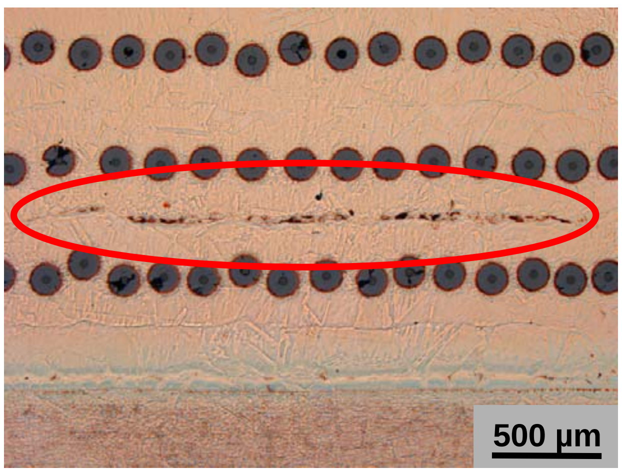
Microscopy analyses after heat flux tests

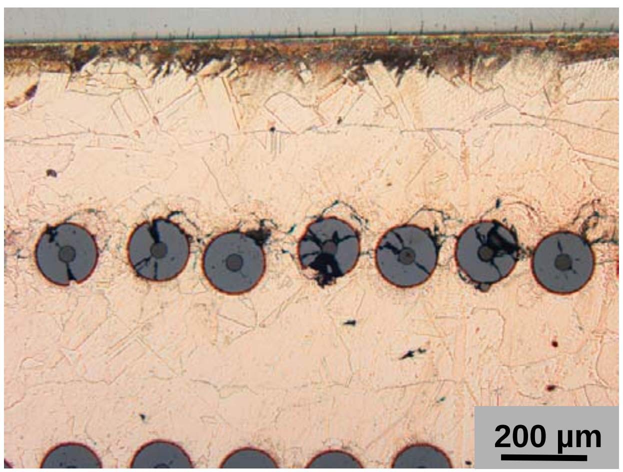


Good bonding between layers







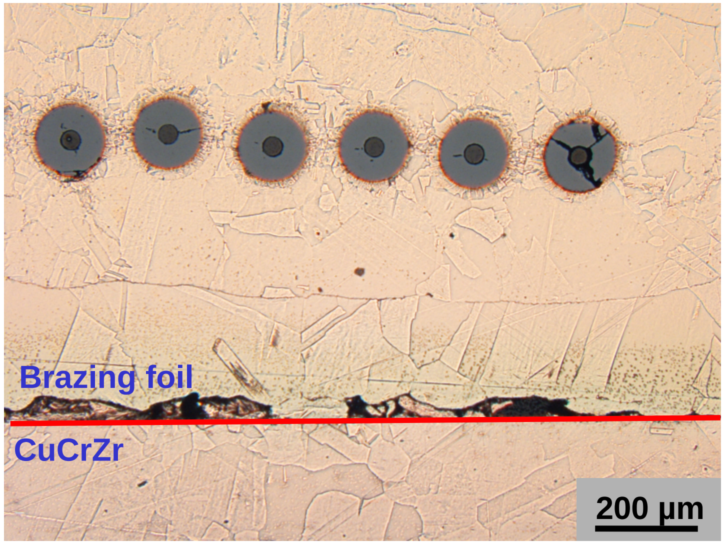


- Localized defects
- No crack growth

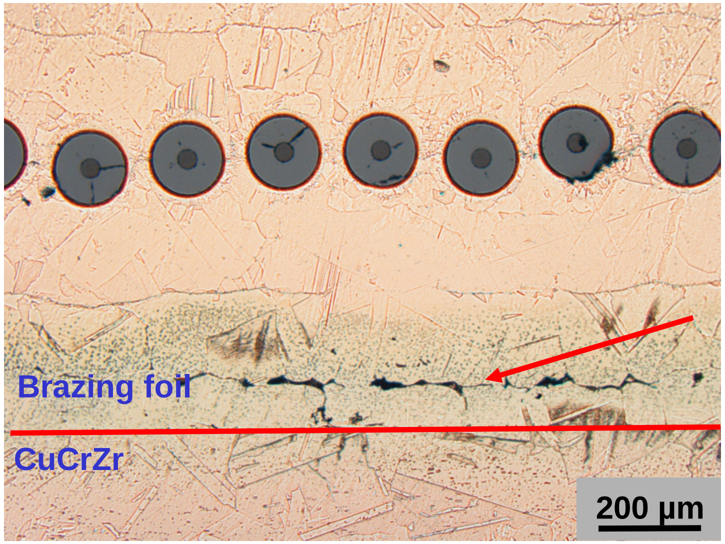
Small cracks within the matrix at outer fibre layers
➔ different CTE, stress

Microscopy analyses after heat flux tests

Bonding MMC/CuCrZr and MMC/W



Cracks between brazing foil and CuCrZr/W

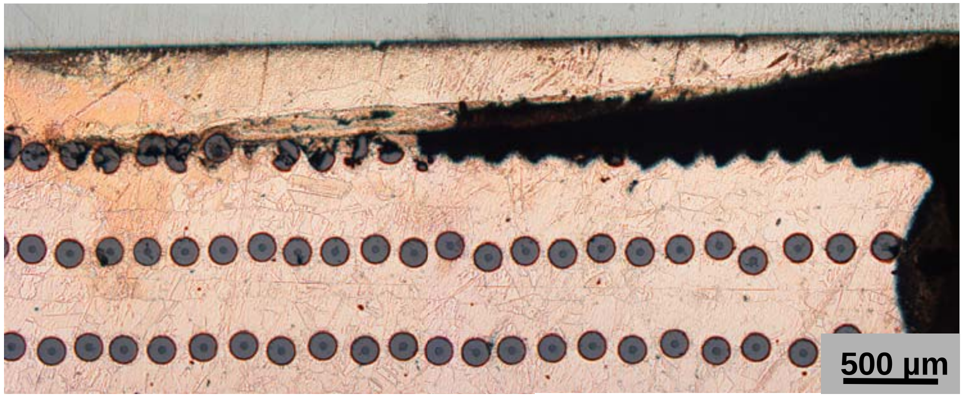


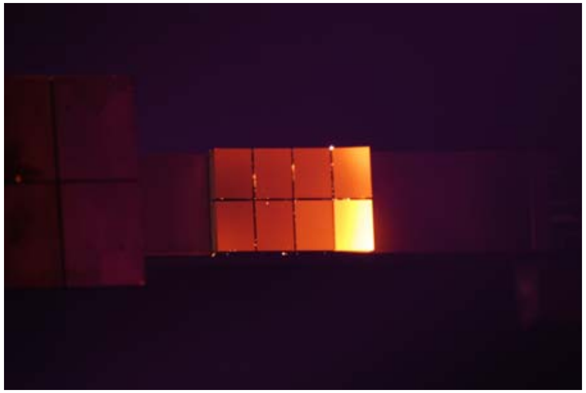
Cracks within the brazing foil (2 brazing foils used)

➔ **Bonding needs improvement**

Microscopy analyses after heat flux tests

Overheating of W-tile - cross section of the damage





Failure at the MMC edge

➔ Insufficient heat flow, overheating of W-tile

Possible interaction of:

- Different CTE, stress concentration
- Highest temperature
- Weak points can lead to failure (bonding between brazing foil and W/MMC, cracks within brazing foil/MMC)

Summary

Heat flux tests - 80 cycles at 10.5 MW/m²

MMC:

- good bonding between the layers
- single cracks, no crack extension visible
- few matrix cracks at the outer layers due to stress

➔ **MMC behaviour promising**

Component:

- Outer layers of MMC – different CTE, stress concentration, highest temperature
- Interface/bonding between the components - brazing technology

➔ **Bonding is a weak point**

Thank you for your attention!