Additive manufacturing as tool to manufacture and maintain plasma facing components

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Outline

- Publications / Fundamentals
- O.1. AM-W: AM of W with density >99% and minimal crack density
- O.2. Joints: Realizing advanced joints (FGM, W/W_w, W/steel, W/copper)
- O.3. W-wire as armour: Realization and testing of W-wire as armour
- O.4. Regeneration: Development of techniques for surface regeneration
- O.5. Advanced heat sink geometries: Development, production and testing
- O.6. Demonstrators of used technologies: Construction of prototype mock-ups

Publications / Fundamentals

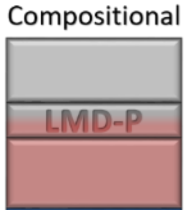
Publications

- V. Ganesh – ID: 33546
  Processing and properties of sintered W/steel-composites for the first wall of future fusion reactor
  https://doi.org/10.3390/jne4010014
- V. Ganesh – ID: 33870
  High heat flux testing of graded W-steel joining concepts for the first wall
  https://doi.org/10.3390/en16093664
- V. Ganesh – ID: 33870
  Determination of mechanical properties of tungsten/steel composites using image based microstructure modelling
  https://doi.org/10.3390/en16093664
- D. Dorow-Gerspach – ID: 33811
  Benchmarking by high heat flux testing of W-steel joining technologies
  https://doi.org/10.1016/j.nme.2023.101508
- J. Tweer– ID: 36194
  First experiments to regenerate the surface of plasma facing components by wire based laser metal deposition
  https://doi.org/10.1016/j.nme.2023.101508

Fundamentals

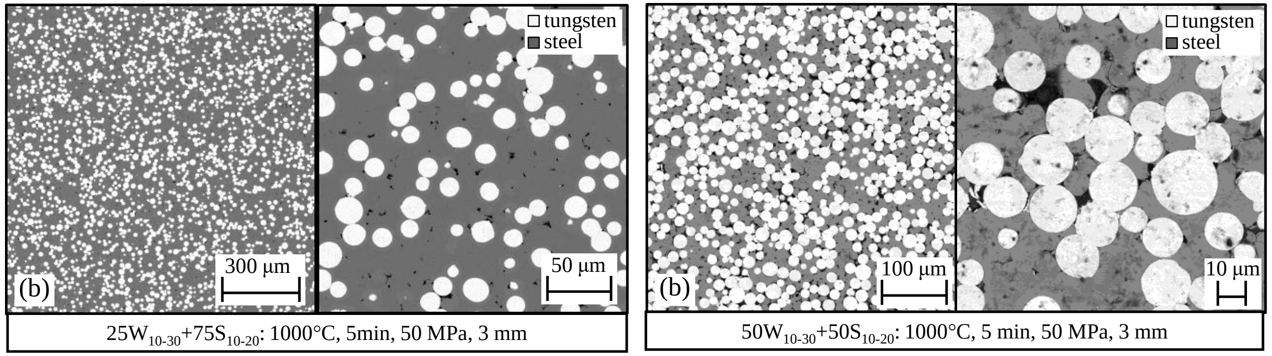
- Financial limitations causing severe limitations on experiments and slowing down progress in nearly all objectives
  - Except: W-Regeneration by LMD-w
- Colleagues from KIT faced also major delays thus they couldn’t support us with SEBM-W samples
  - The geometrical joint concept couldn’t be realized let alone tested yet
- Prototype mockups with 25x25 mm² instead of standard 12x12mm² tile sizes will be realized and tested this year

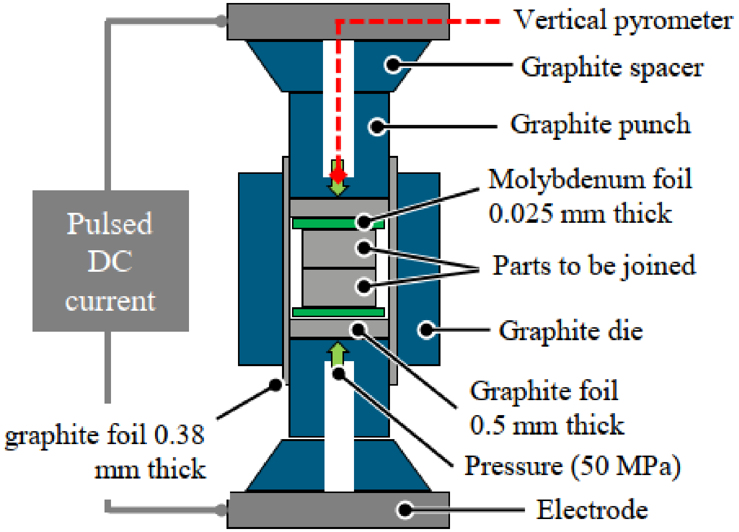
O.2. Joints – Compositional FGMs

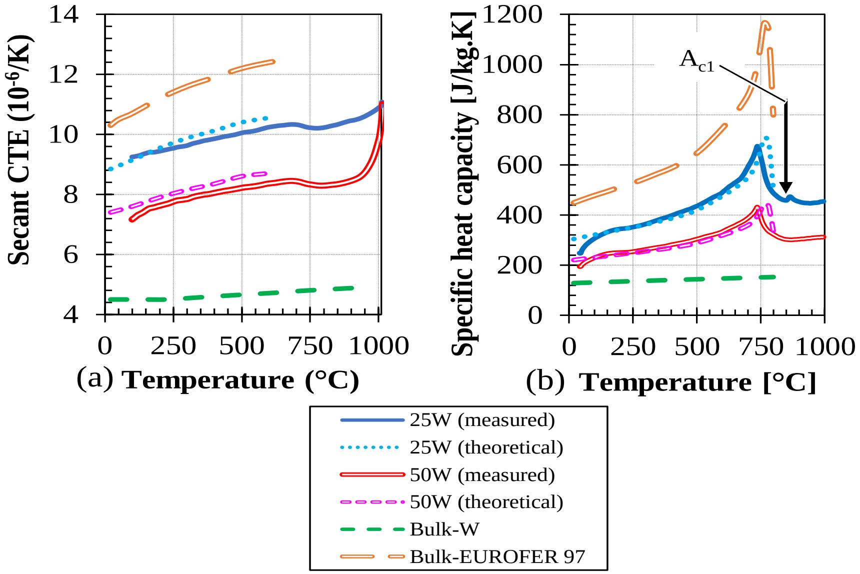


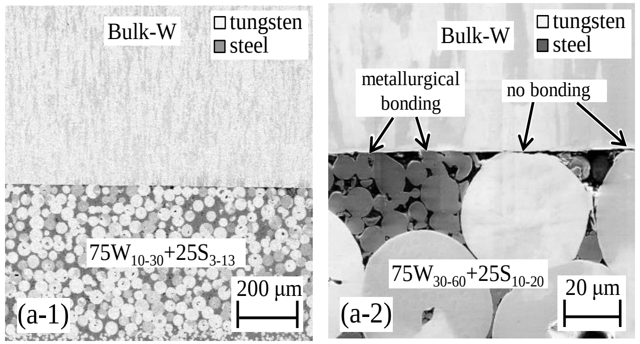
- Various different methods were used
  - APS, EDS, SPS producing single & full stack
  - First benchmark test indicated that thin metal film together with SPS-FGM should outperform ref.
  - New samples were made with 10 µm V or Ti film
  - Benchmarktest including W_fW on steel are planed

Spark Plasma Sintering

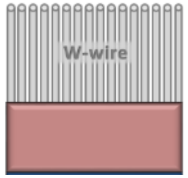






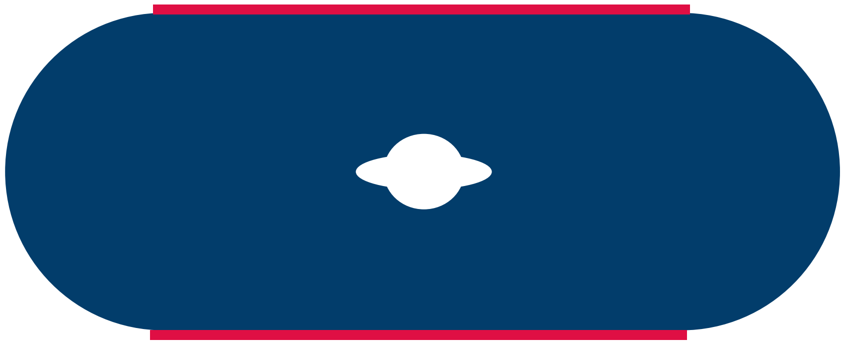


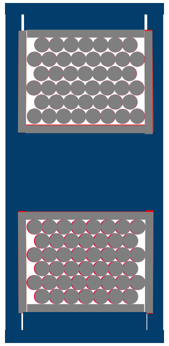
O.3. W-wire as armor



- Larger spool design
  - Enough to cover 460 cm², 3 mm thick
  - Cylindrical shape did not improve stacking quality or thickness before loosing wires
  - More effort to form plan parallel slices
  - ➲ **Cylindrical design dismissed**

- New Design
  - Rectangular with half circle at the end
    - Larger portion of wires easily useable
  - Inlet of 125 µm W-foil as “wall” for better mechanical stability at the sides
  - **Spool is built, foil and wire are ordered**





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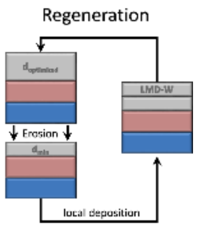
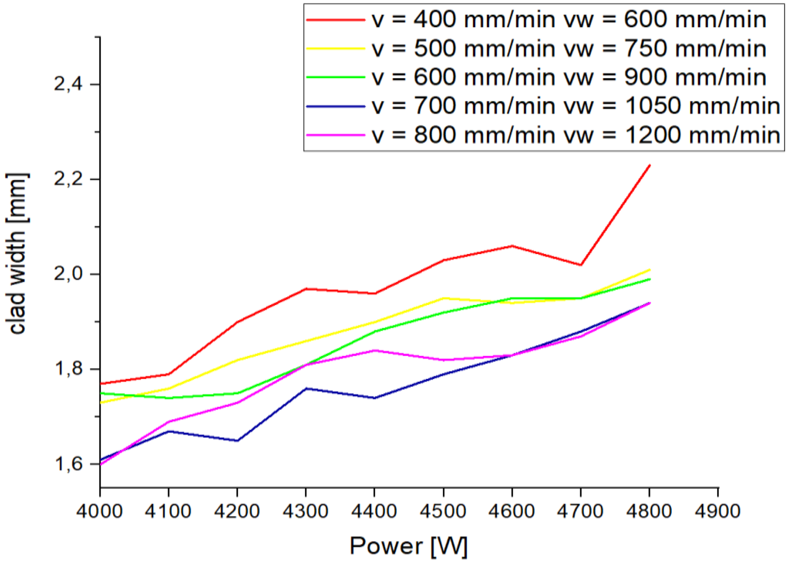
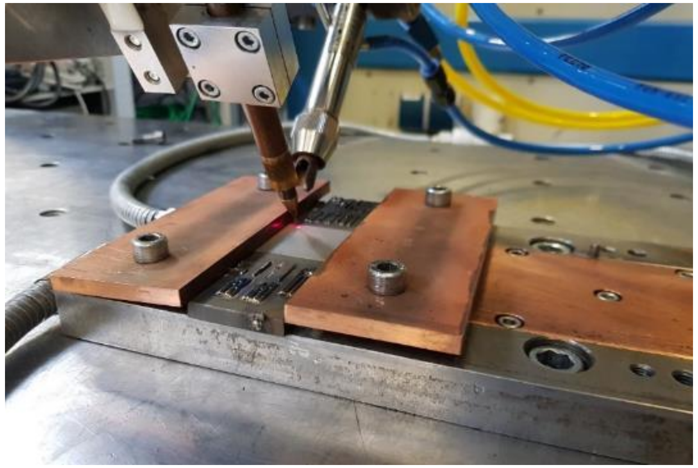
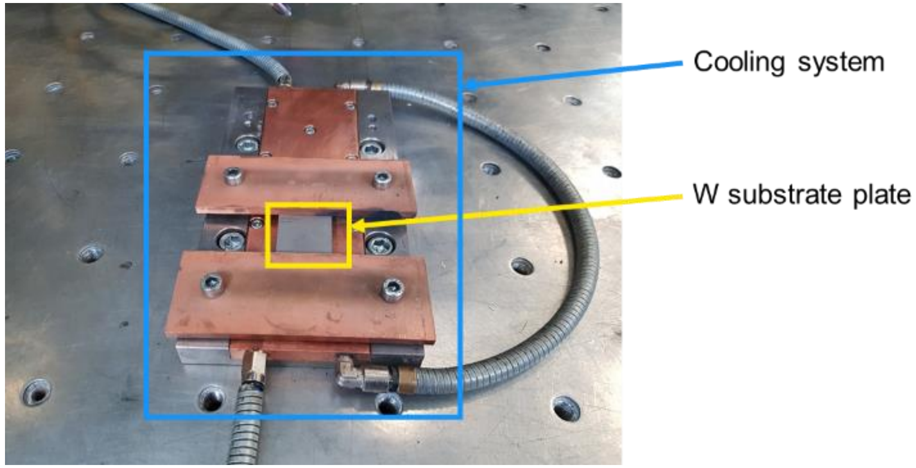
O.4. Regeneration



- LMD-W at IPT Aachen
  - Ar flow, 4 kW IR laser, W on steel, W, W_w
  - Porosity, Cracks have to be reduced
- Cooling holder to improve substrate temperature control during the deposition
  - Parametric studies are performed -> work ongoing
  - Width nicely tailorable by power and velocity

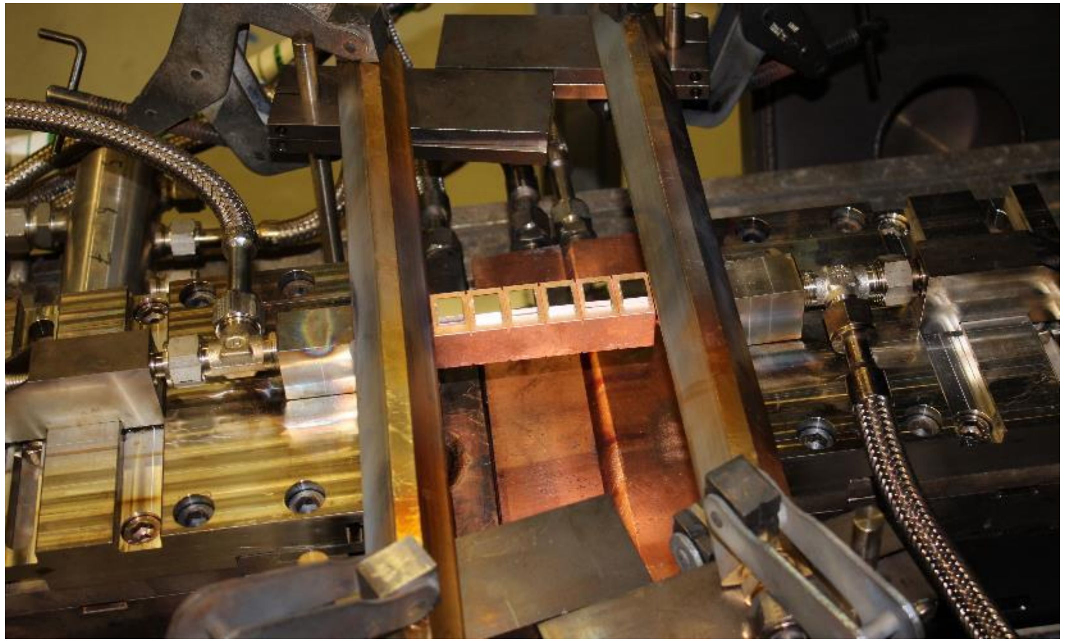


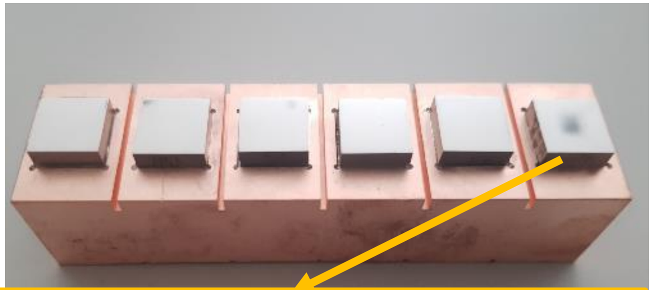




O.4. Regeneration

- Predamaging in JUDITH 2
  - 12 x 12 mm² W-tiles on Cu-cooling brazed
  - Tansient heat load: 10^5 Thermoshocks, 0.5 ms with L_{abs} = 0,55 GW/m2 (F_{HF} = 12 $MWs^{0,5}/m^2$) at base temperature of T_{base} = 700°C





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O.4. Regeneration

- Deposition on damaged area

  1: Layer with standard condition

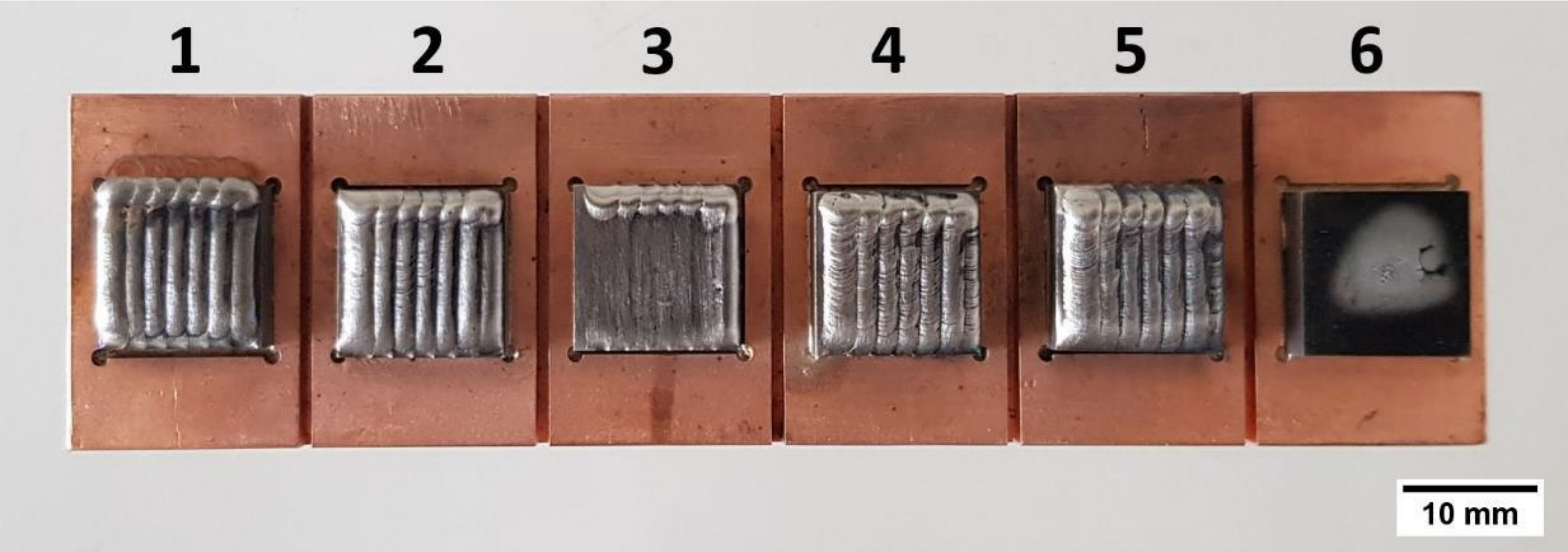
  2: Lower deposition velocity

  3: Remelting damaged area

  4: Remelting + standard Layer

  5: Remelting + lower velocity layer

  6: Reference

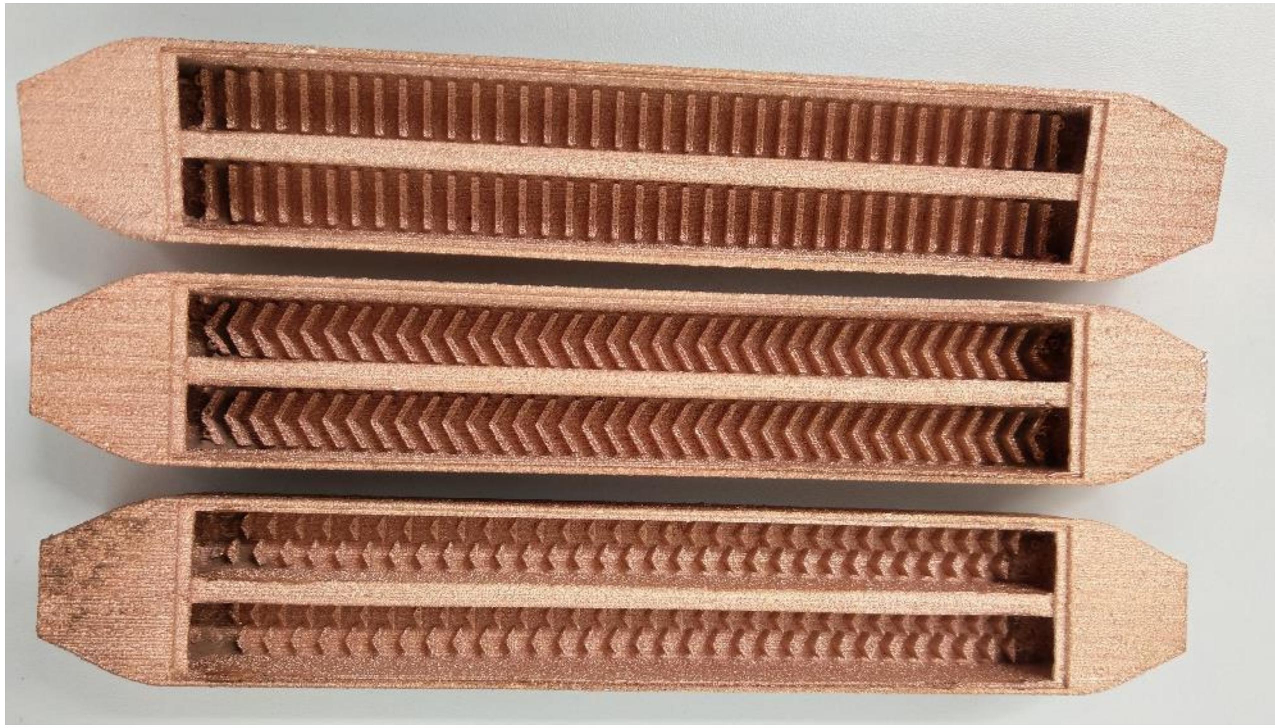


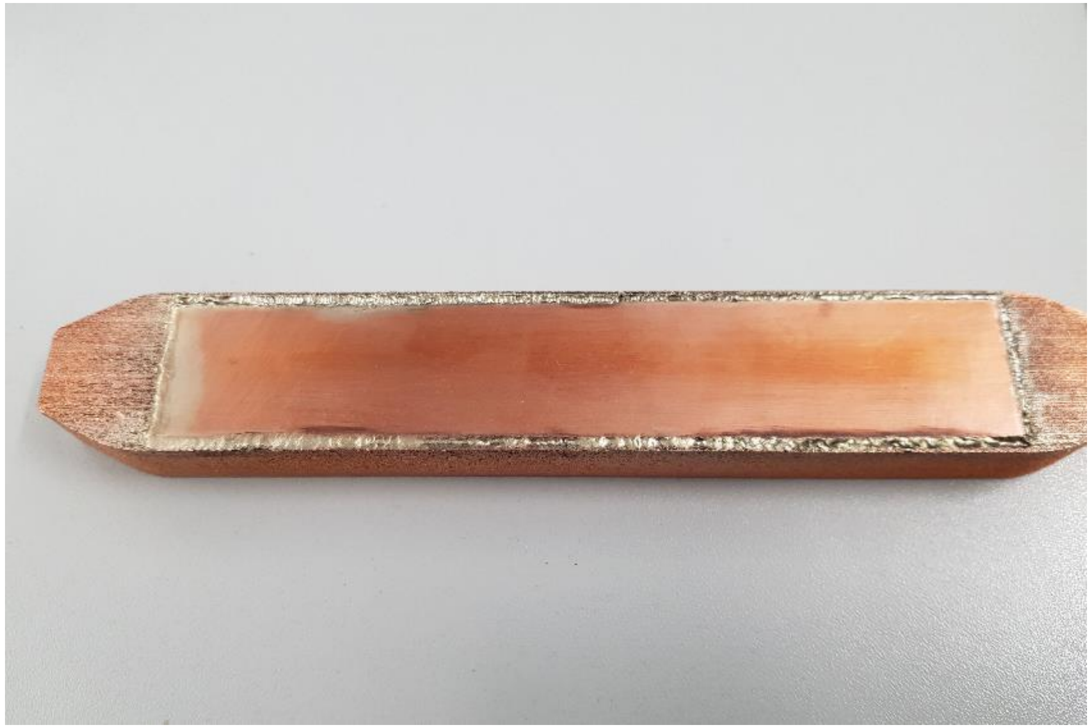
- Metallographic analysis ongoing
  - Cross sections at start, center and end of each weld bed
  - Microstructual investigation including hardness measurements

O.5. Advanced heat sink geometries

JÜLICH Forschungszentrum

- Further geometries with Cu was printed at IFAM
  - Hydrodynamic and high heat flux tests to assess potential and impact of designs are planned
  - Simple thermal comparative FEM simulations to assess HTC and disentangle area from flow dynamics
  - Backplate soldering failed, two welding tries failed as well, a last try with higher energy is ongoing





O.6. Prototype mock-up: LMD-w on W

W-tiles: „monoblock pair“, 8 (reference) or 7 mm thick (for deposition)

Cu-cooling structure fitting JUDITH 2 clamping

PFC for HHF testing of LMD-w deposites

O.6. Testing conditions for a LMD-w PFC

- Test conditions to mimic divertor condition
  - Aiming for the same surface temperatures at
  - Elevated cooling water temperature and 8 mm thick W-tiles for comparable temperature profile
  - ➲ **Simulate the center of a MB with flat tile design**

- 2 Components are planned
  - One layer with and w/o remelting
  - Two layers with 0 and 90° between depositions
  - 10 MW/m², 15 MW/m² and 20 MW/m²
    - Each at least 200 cycles
  - Transient loadings on deposited material

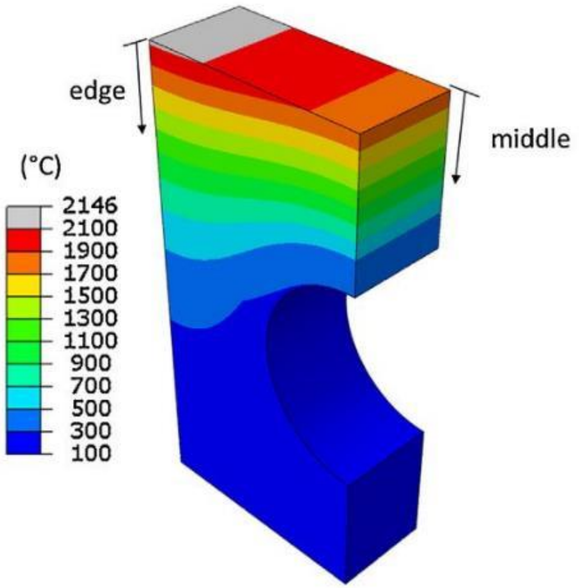
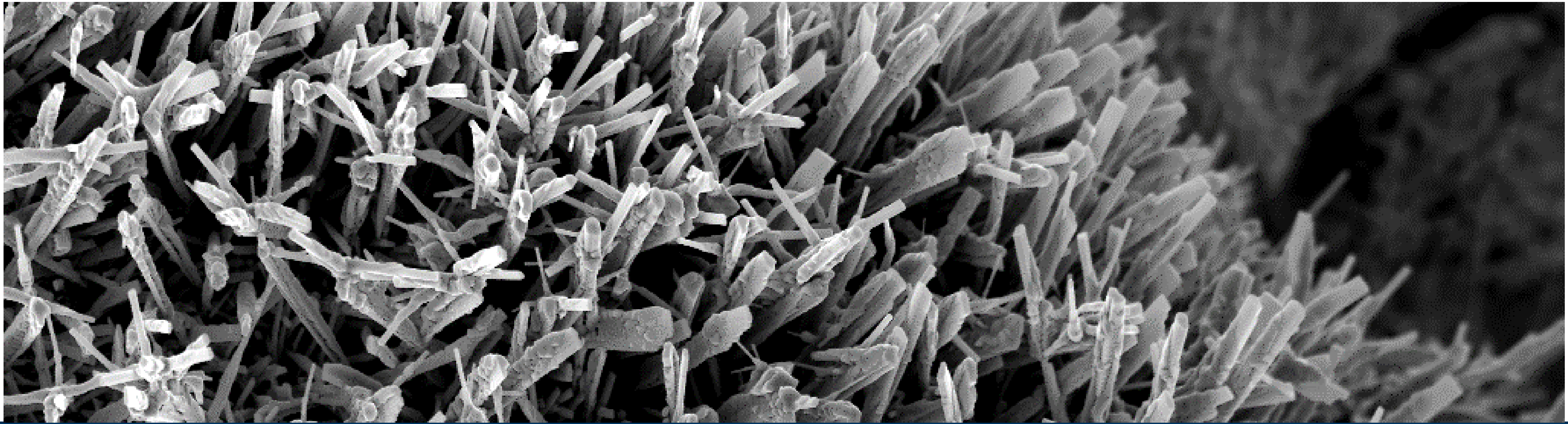


Fig. 4. Temperature field in the divertor target under stationary HHF load of 20 MW/m².

Table 3
Calculated temperature range on the armor surface during steady state HHF loading.

Heat flux loads	Temperature ranges
10 MW/m²	950–1058 °C
15 MW/m²	1411–1612 °C
20 MW/m²	1864–2146 °C

M. Li and J.-H. You; Nuclear Materials and Energy Nuclear Materials and Energy, vol. 14, pp. 1-7, 2018, doi: 10.1016/j.nme.2017.12.001



Thank you for your attention

Outtakes