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.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
  - Benchmark test including W₁W on steel are planned

- Spark Plasma Sintering

- Graphical representations of experimental results:
  - Compositional FGMs
  - Bulk-W and Bulk-EUROFER 97
  - CTE and Specific Heat Capacity measurements

- Various microscopic images showing joint formation and bonding characteristics:
  - Metal foil, Graphite, Molybdenum, Graphite punch
  - Parts to be joined, Graphite die, Graphite foil, Molybdenum foil
  - Pressure and temperature conditions are specified for each experiment.

- Diagrams illustrating the process parameters and results:
  - Pulsed DC current, Vertical pyrometer
  - Graphite spacer, Electrode, Pressure (50 MPa)
  - Compositional FGMs with measured and theoretical values.
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**
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
- Transient heat load: $10^5$ Thermostocks, 0.5 ms with $L_{\text{abs}} = 0.55 \text{ GW/m}^2$
  ($F_{\text{HF}} = 12 \text{ MWs}^{0.5}/\text{m}^2$) at base temperature of $T_{\text{base}} = 700^\circ \text{C}$
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
- Microstructural investigation including hardness measurements
O.5. Advanced heat sink geometries

- 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 deposits
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
Thank you for your attention
Outtakes