Utilization of Additive Manufacturing in Nuclear Power Industry

FNSPE at CTU & COMTES FHT a.s.

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R8 LMAG meeting

Prague, Czech Republic

27th of October, 2022

Outline

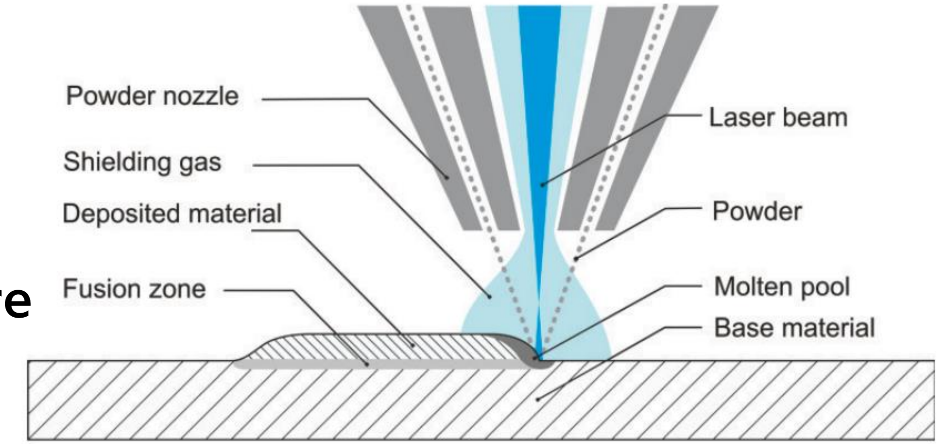
The aim of the project

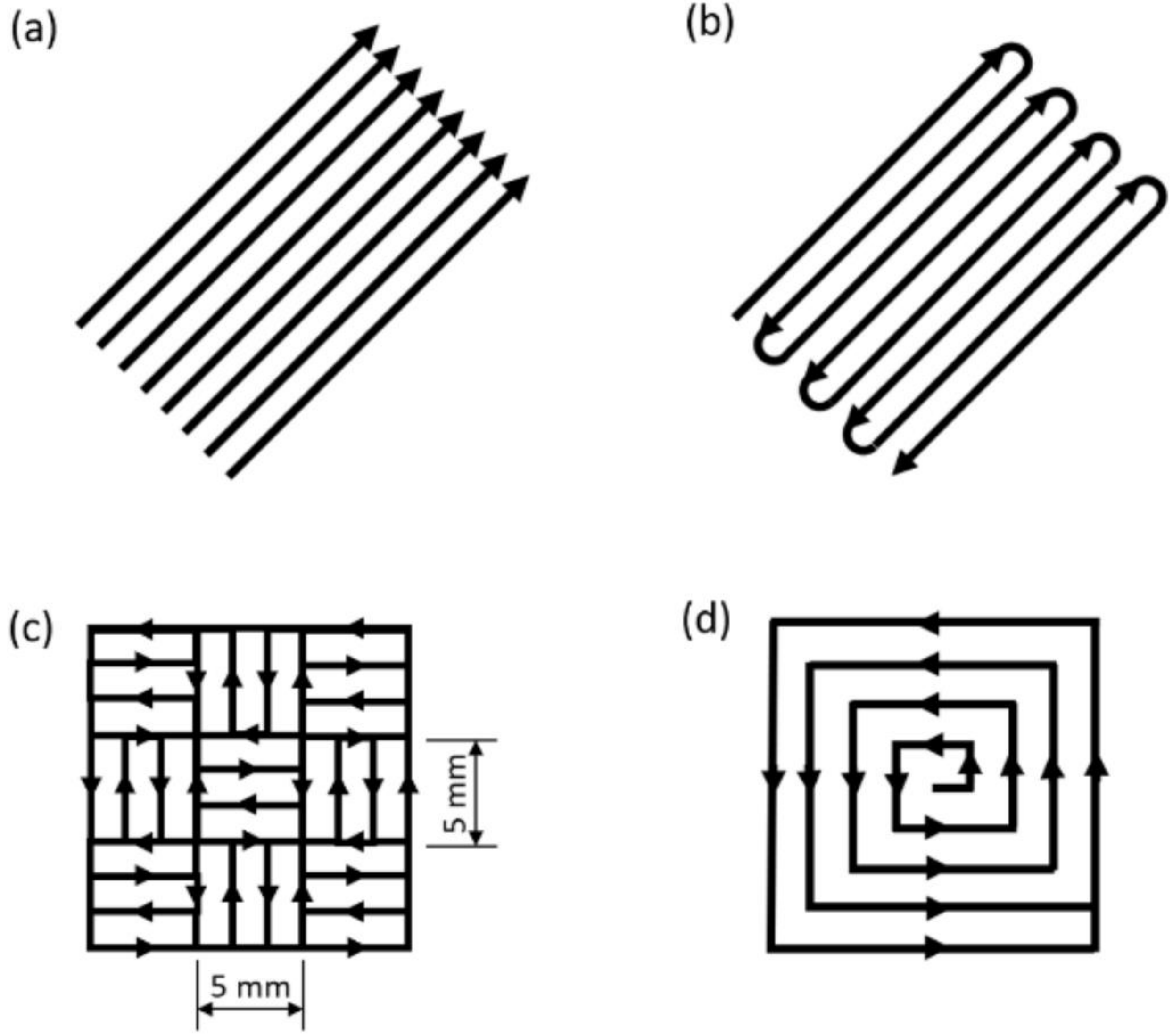
- Research on additive manufacturing (AM) methods with emphasis on Direct Energy Deposition method (DED)
- Use of additive manufacturing (AM) methods in Nuclear Power Industry
- Printing samples via DED and obtaining material properties
- Propose optimal manufacturing parametres based on the obtained data

Method	Technology	Material
Direct Energy Deposition	Laser Direct Energy Deposition Electron Beam Direct Energy Deposition	Metals
Powder Bed Fusion	Selective Laser Sintering Selective Laser Melting Electron beam Melting	Polymers Metals Ceramics
Vat Photopolymerization	Stereolithography Digital Light Processing	Photopolymers Ceramics
Sheet Lamination	Laminated Object Ultrasonic Consolidation	Metals Ceramics Plastic sheet
Material Extrusion	Fused Deposition Modeling	Polymers
Material Jetting	Polyjet Multi-Jet Modeling	Polymers Photopolymers Wax
Binder Jetting	3D printing Voxeljet Exone	Metals Polymers Ceramics

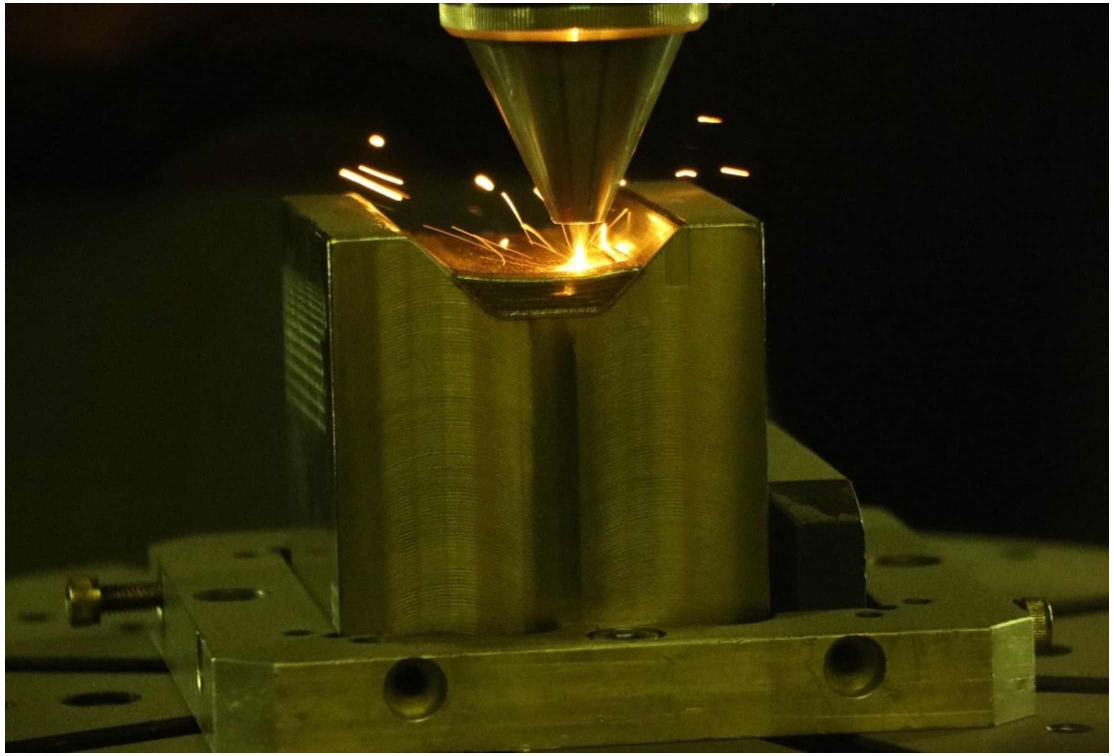
Direct Energy Deposition (DED)

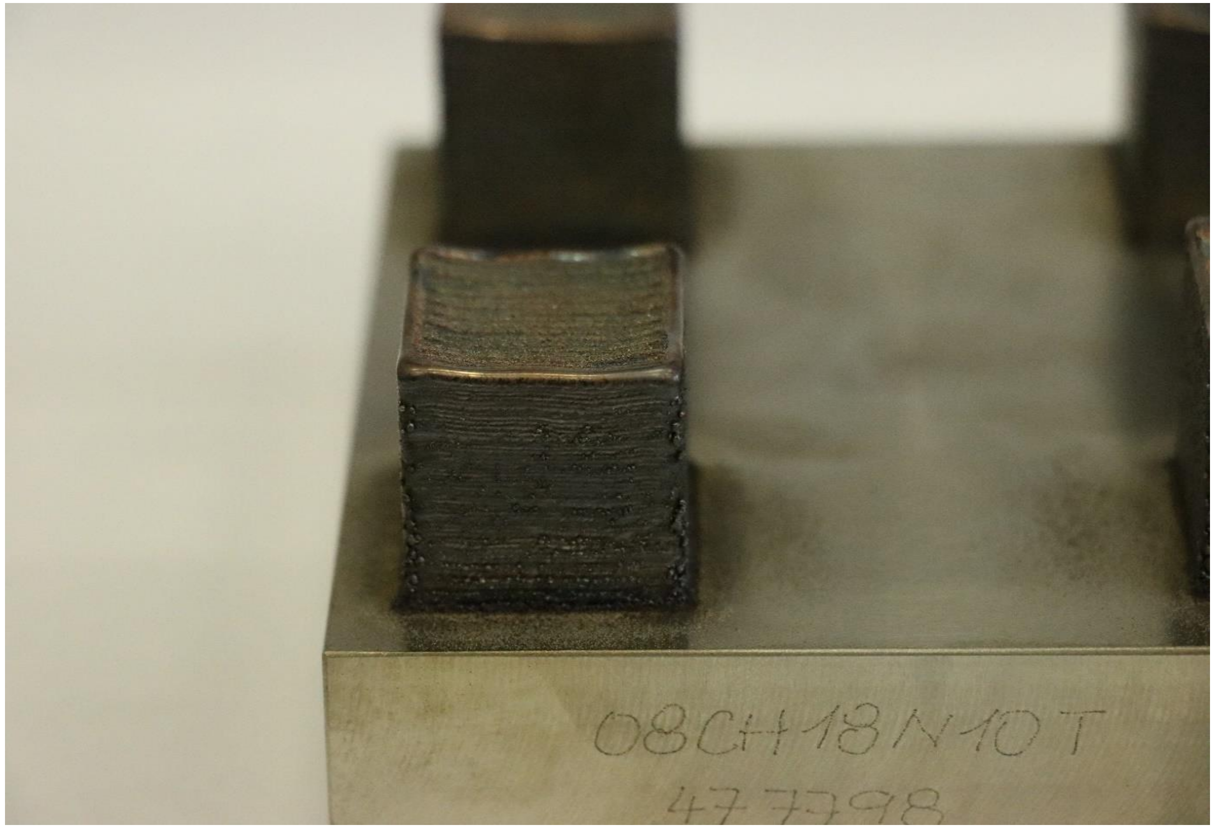
- Faster but less precise manufacturing process
- Graduated manufacturing
  - ❑ Availability to print from multiple materials or to do gradient transitions
- Multi-axis printing (up to 5 axis)
- Cladding, defect repairing
- Printing via laser or an electron beam
  - ❑ Inert or shielding gas (laser) – powder and wire based
  - ❑ Vacuum (electron beam) – wire based





Printing strategy: a) Zig, b) ZigZag, c) Chessboard, d) Spiral

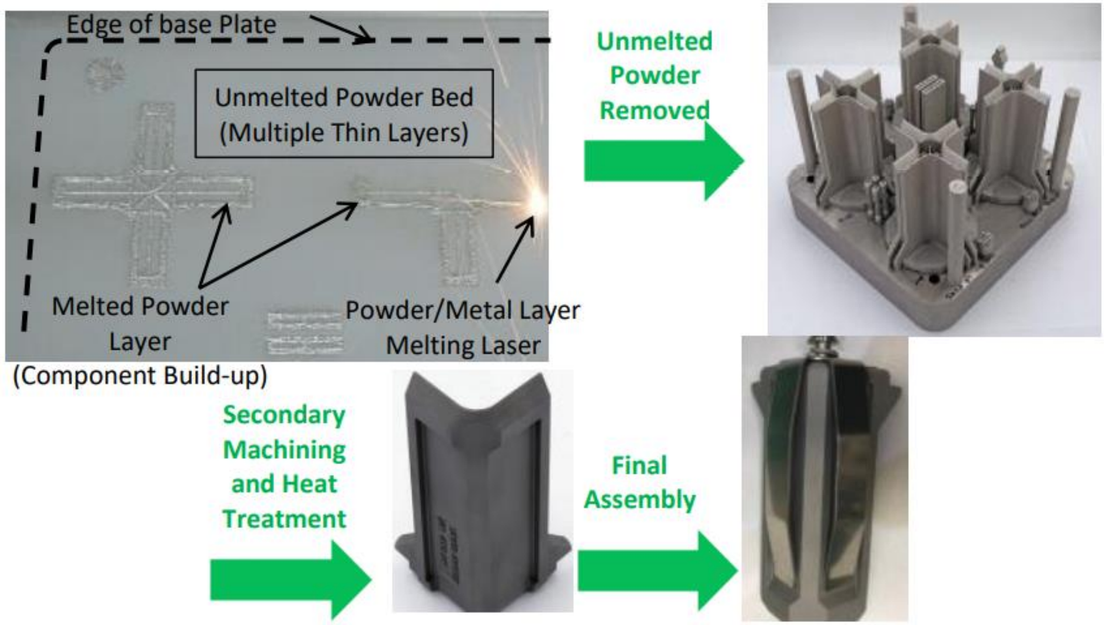



08CH18N10T

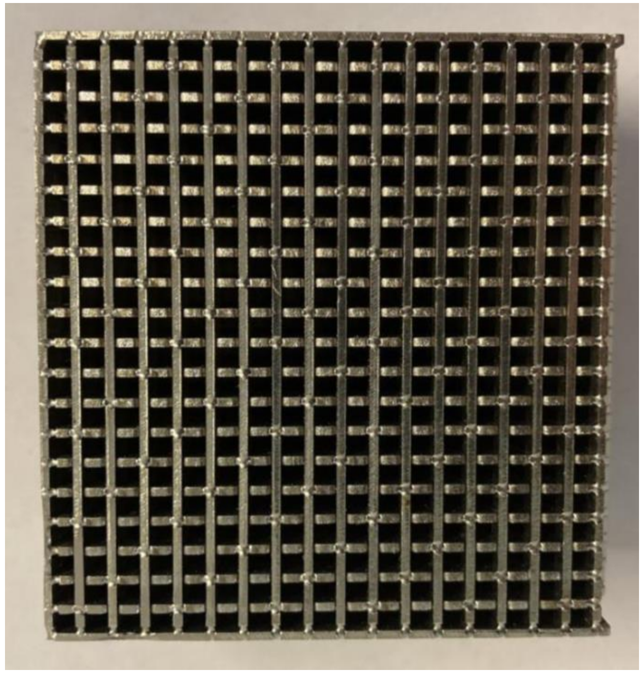
AM in nuclear power industry

- No standards qualifying use of AM in nuclear power industry
- Huge affection of deposition parametres on material properties

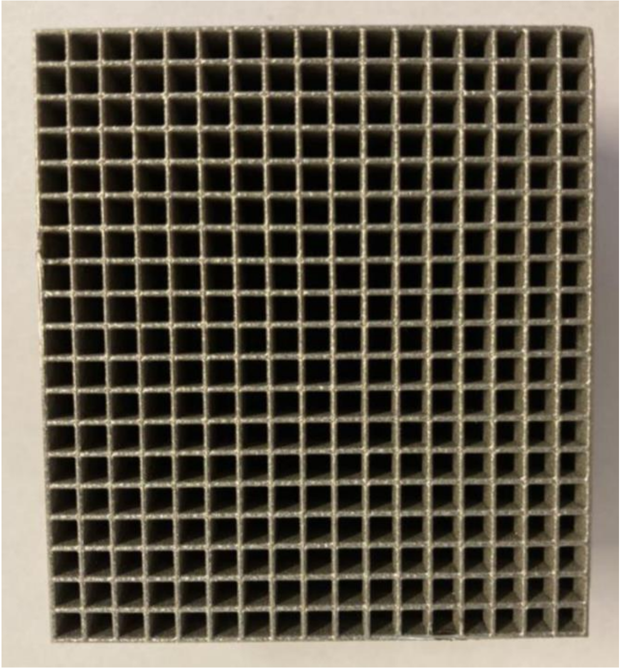
- Framatome –10x spacer via PBF for BWR reactors
- Framatome, ORNL, TVA – 4x channel fastener via PBF from SS316L
- Westinghouse – StrongHold AM filter (debris filter)
- Framatome – printed Uranium alloys



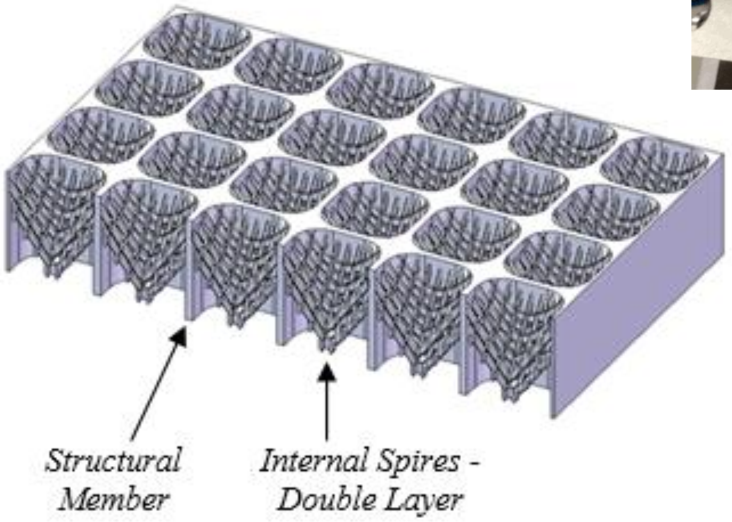
Channel fastener – production process



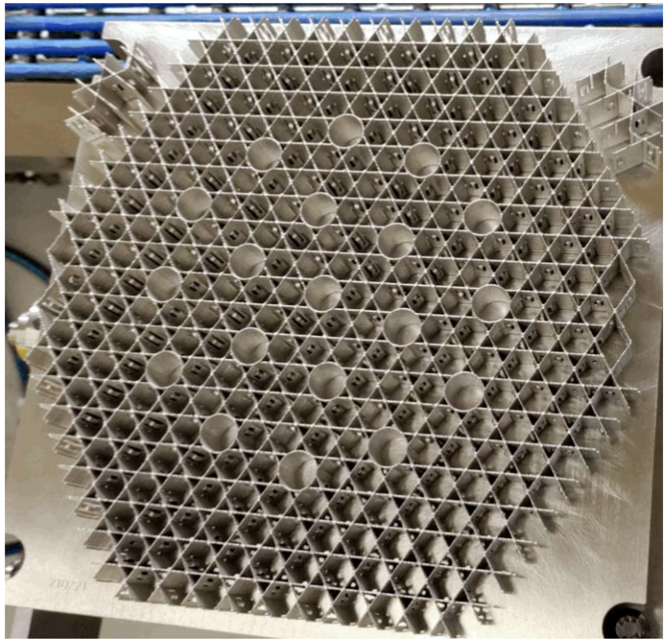
StrongHold filter



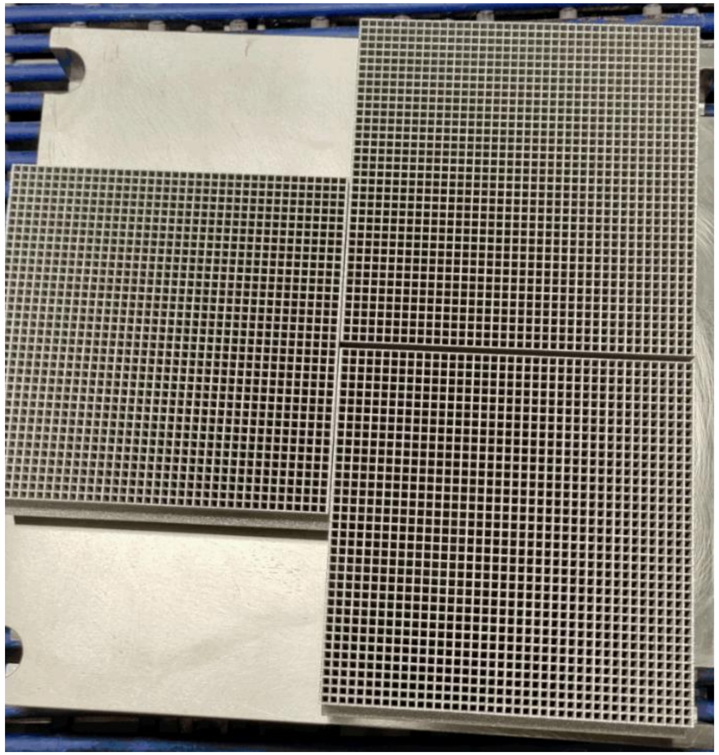
StrongHold AM filter



PWR bottom nozzle for debris capture



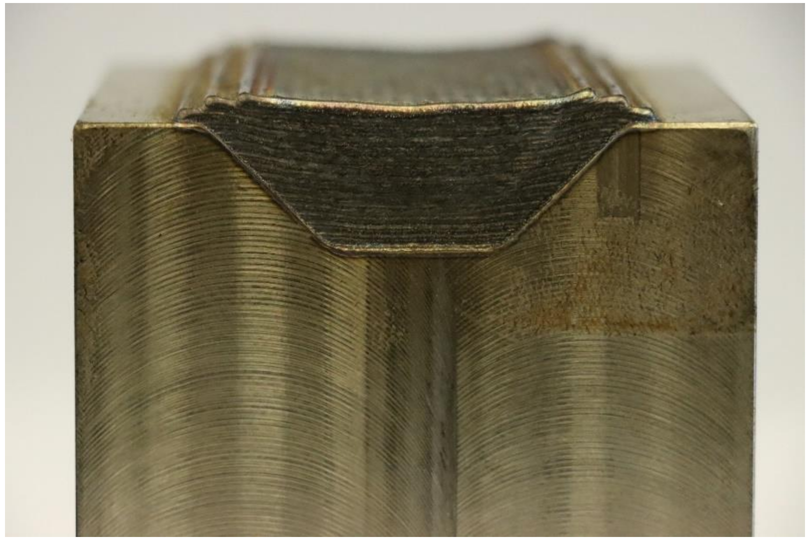
VVER-1000 spacer grid

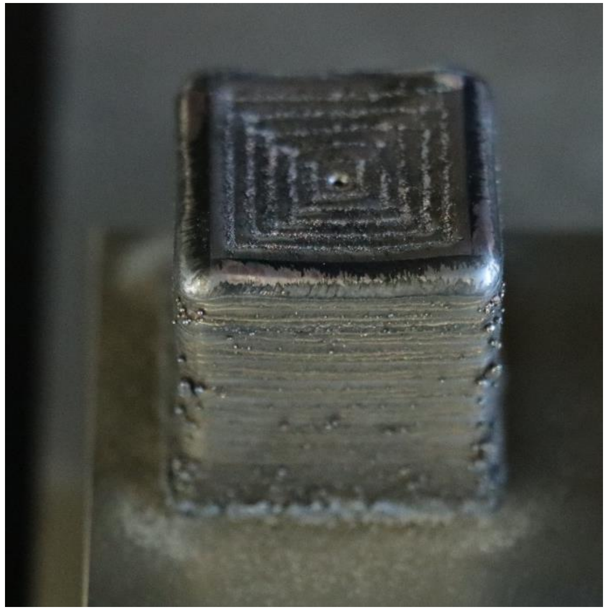


TRITON 11 fuel filters

Material and Methods

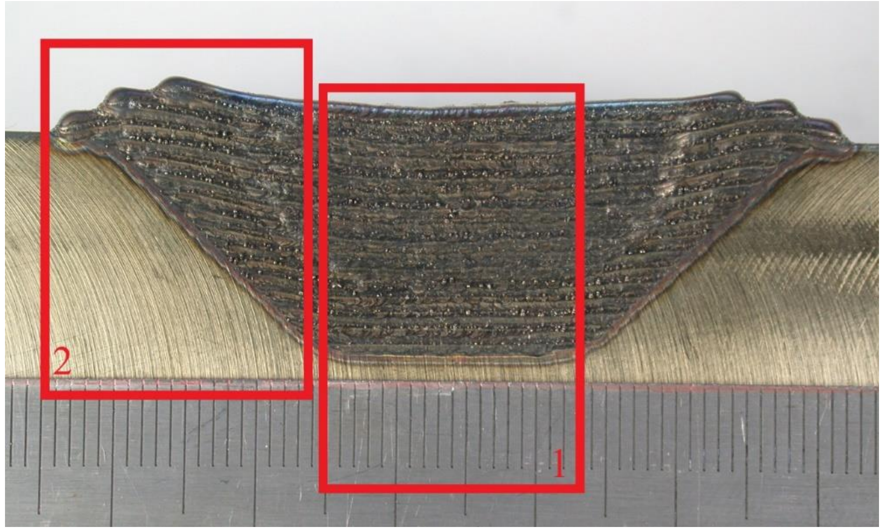
- 8x cube shaped samples were printed via DED (20x20x20 mm)
  - ❑ Samples printed from 08CH18N10T (powder particles size 45-120 µm)
- Samples divided into 2 groups based on the deposition module (optics)
  - ❑ 4x SDM 2400 (diameter of laser beam 2400 µm)
  - ❑ 4x SDM 1600 (diameter of laser beam 1600 µm)
- Repair of simulated defect on a cube shaped sample (80x80x80 mm)
  - ❑ Cube was made via conventional methods (forged) from 08CH18N10T
  - ❑ Repair done via DED from 08CH18N10T

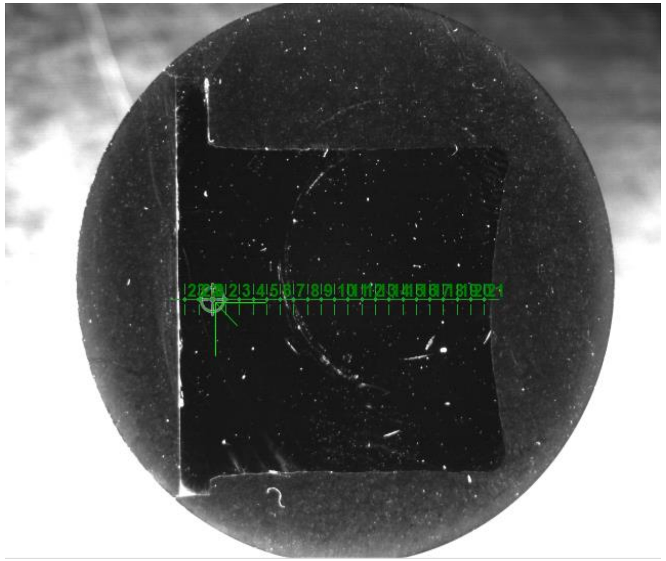


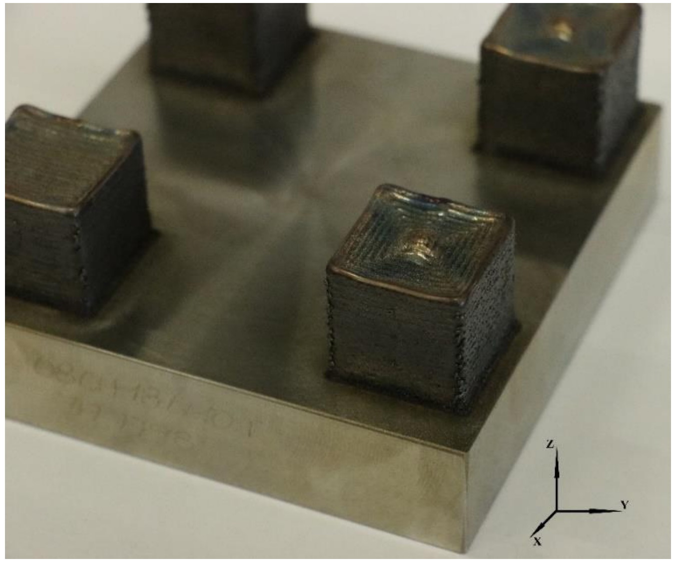


Experiment

- Samples cut in different planes
- Mounted, abraded, etched
- LOM screens
- Vickers microhardness (HV1)
- Metallography







Results – hardness of deposited samples

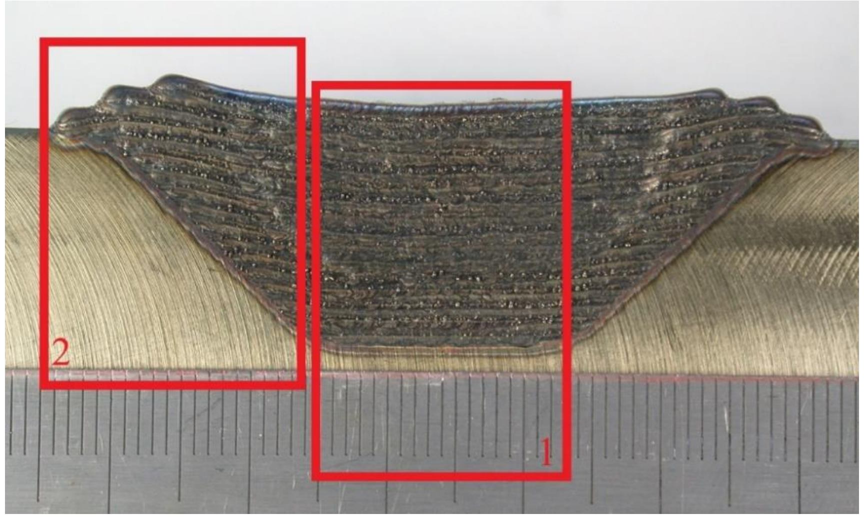
- HV5 was measured to be 175 ± 4.9 at RT for non-deposited 08CH18N10T
- HV0.5 was measured to be 165 on machined specimens (at 260 °C)
- HV0.3 of AISI 321 is 175.17 at RT (equivalent to 08CH18N10T according to ASTM/ASME)

Vickers hardness (HV1 load) at RT								
Sample	1_4_ZigZag YZ	2_4_ZigZag XZ	3_4_Spiral YZ	4_4_Spiral XZ	1_6_ZigZag YZ	2_6_ZigZag XZ	3_6_Spiral YZ	4_6_Spiral XZ
Average	179.04	178.48	172.75	173.71	180.83	189.91	176.19	175.32
Standard deviation	7.73	4.99	7.99	6.06	9.74	8.83	10.49	9.01

Results – hardness of repaired defect

- HV5 was measured to be 175 ± 4.9 at RT for nondeposited 08CH18N10T
- HV0.5 was measured to be 165 on machined specimens (at 260 °C)
- HV0.3 of AISI 321 is 175.17 at RT (equivalent to 08CH18N10T according to ASTM/ASME)

Vickers hardness (HV1 load) at RT				
Sample	1_YZ	1_XZ	2_YZ	2_XZ
Average	210,47	213	210	215,33
Standard deviation	9,74	9,67	9,17	8,11



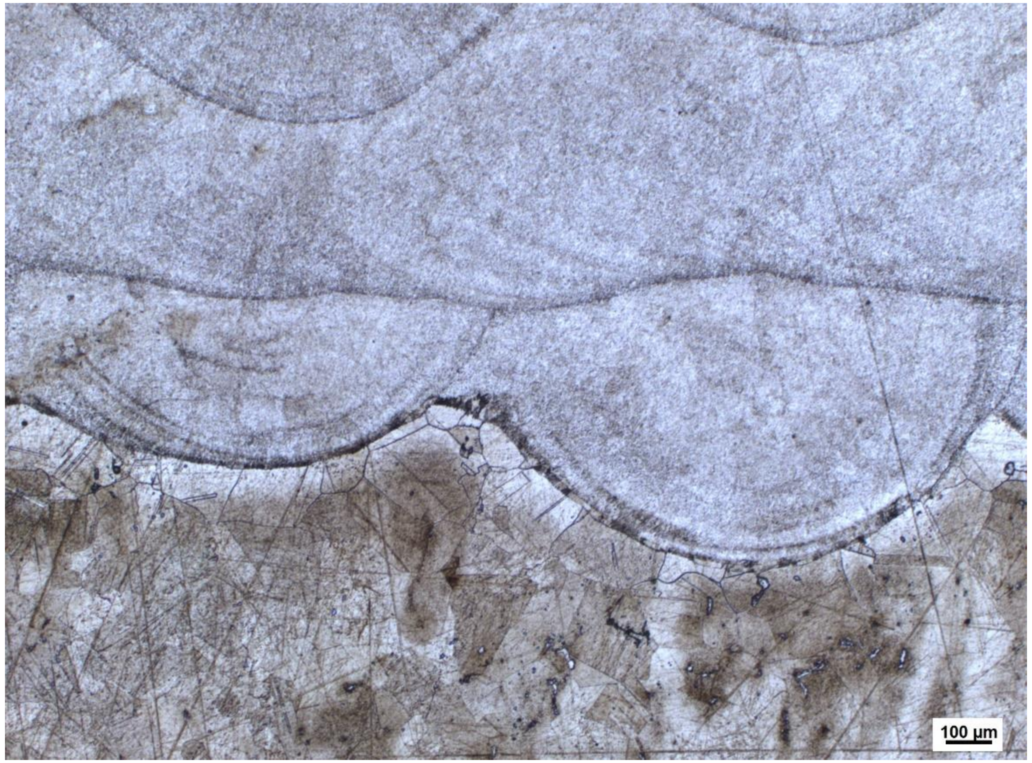
Results – metallography

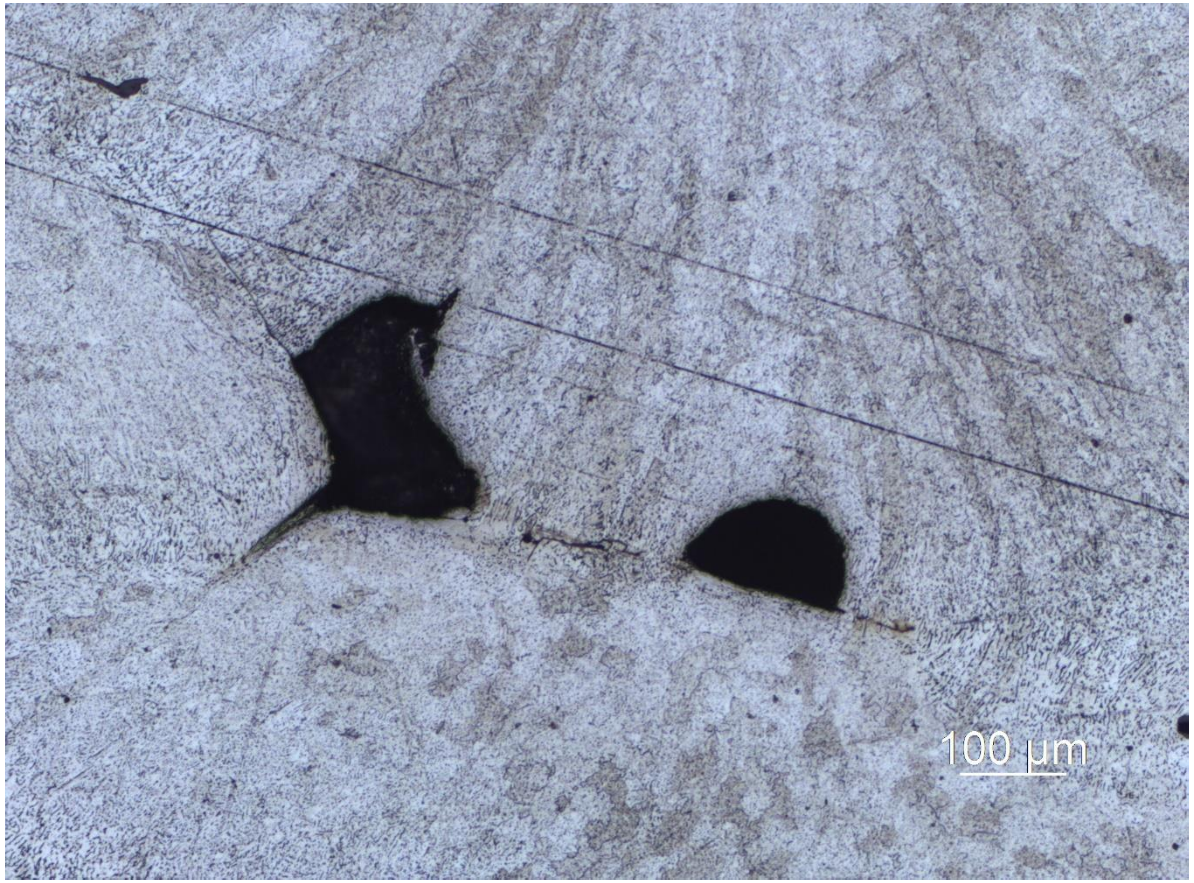
- Columnar and small equiaxed grains
  - From the outside of the meltpool into its center

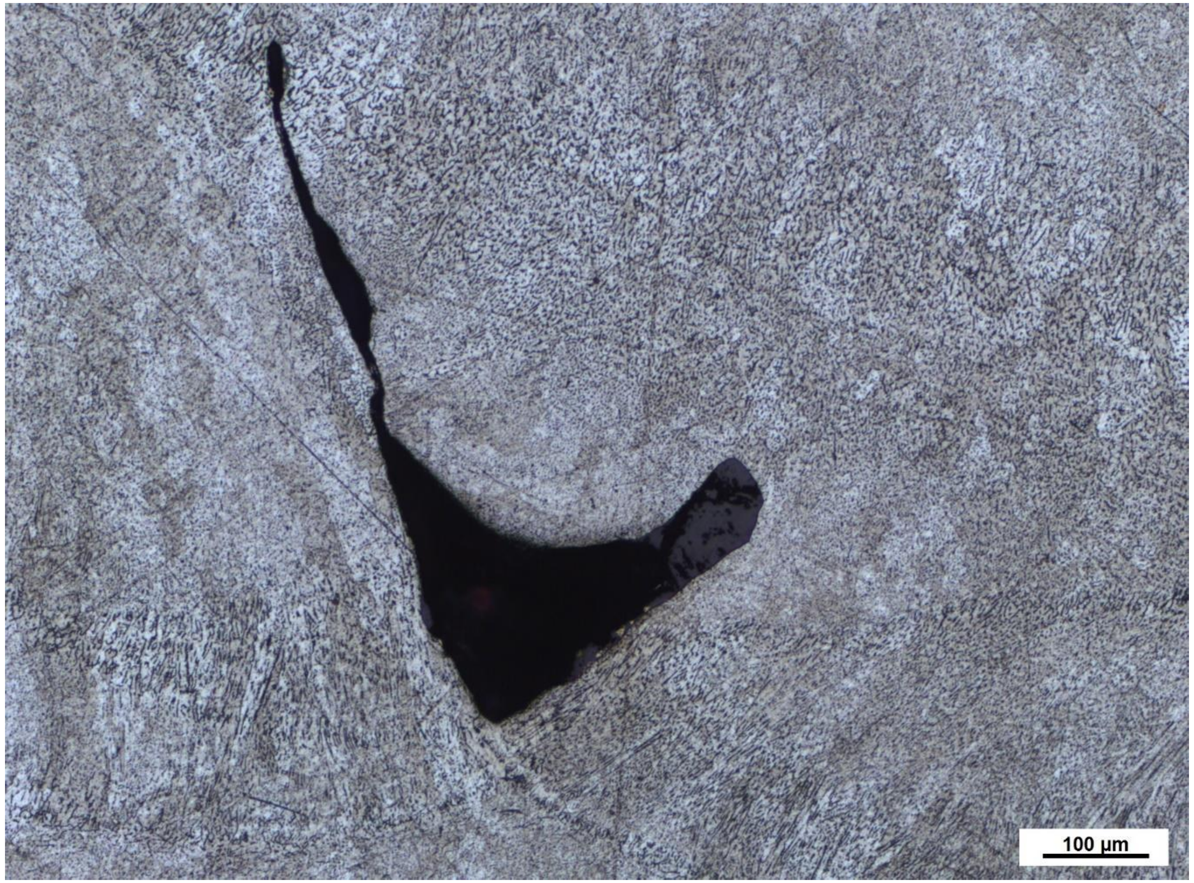
- Smaller grains when SDM 1600 is used

- Different meltpool sizes due to the DMT

- Pores and cracks are observed on the transition area of meltpools




100 µm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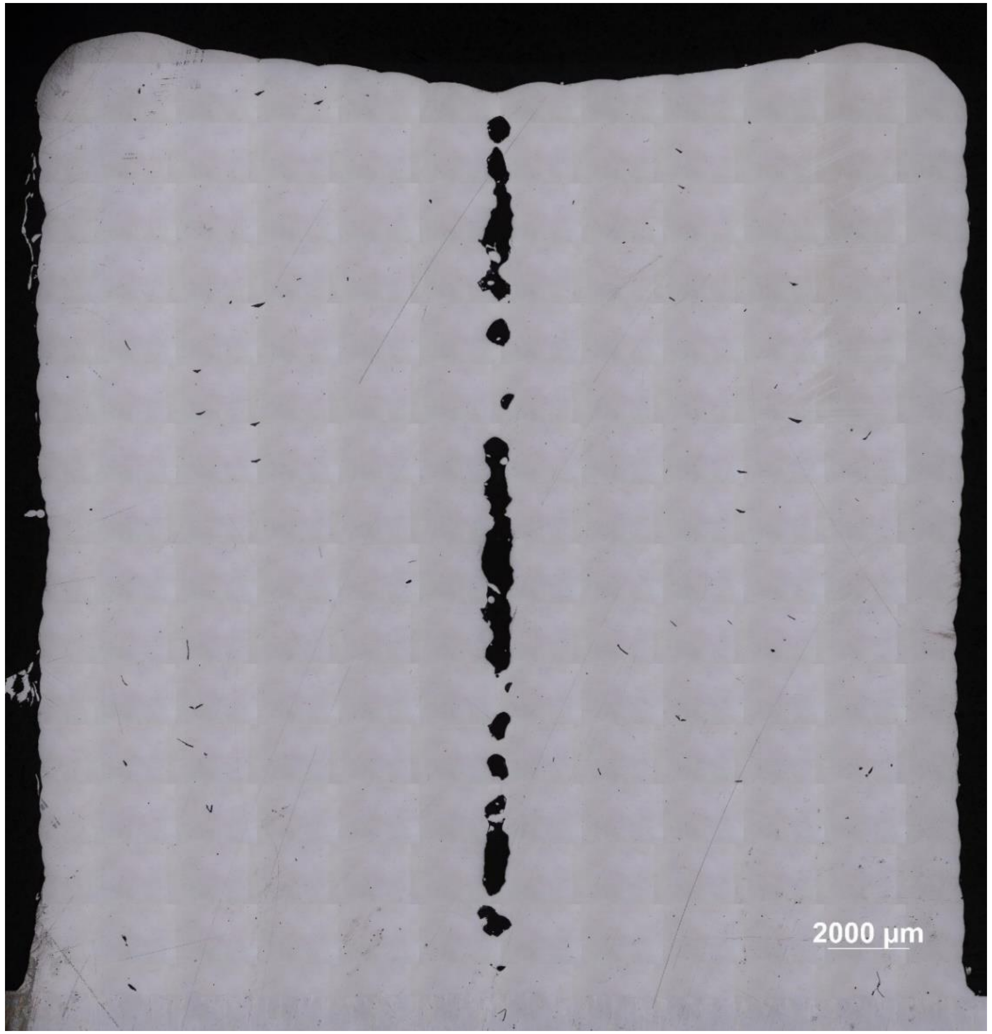
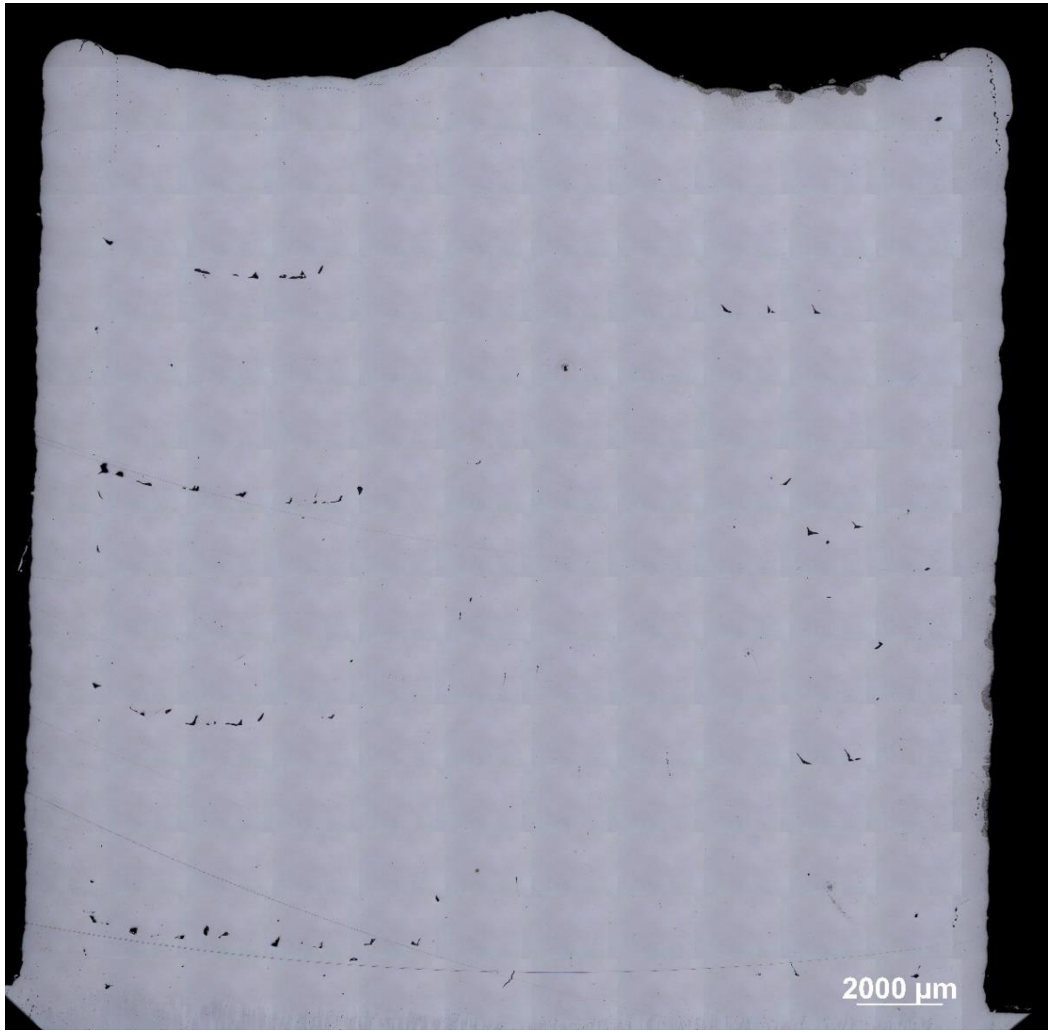
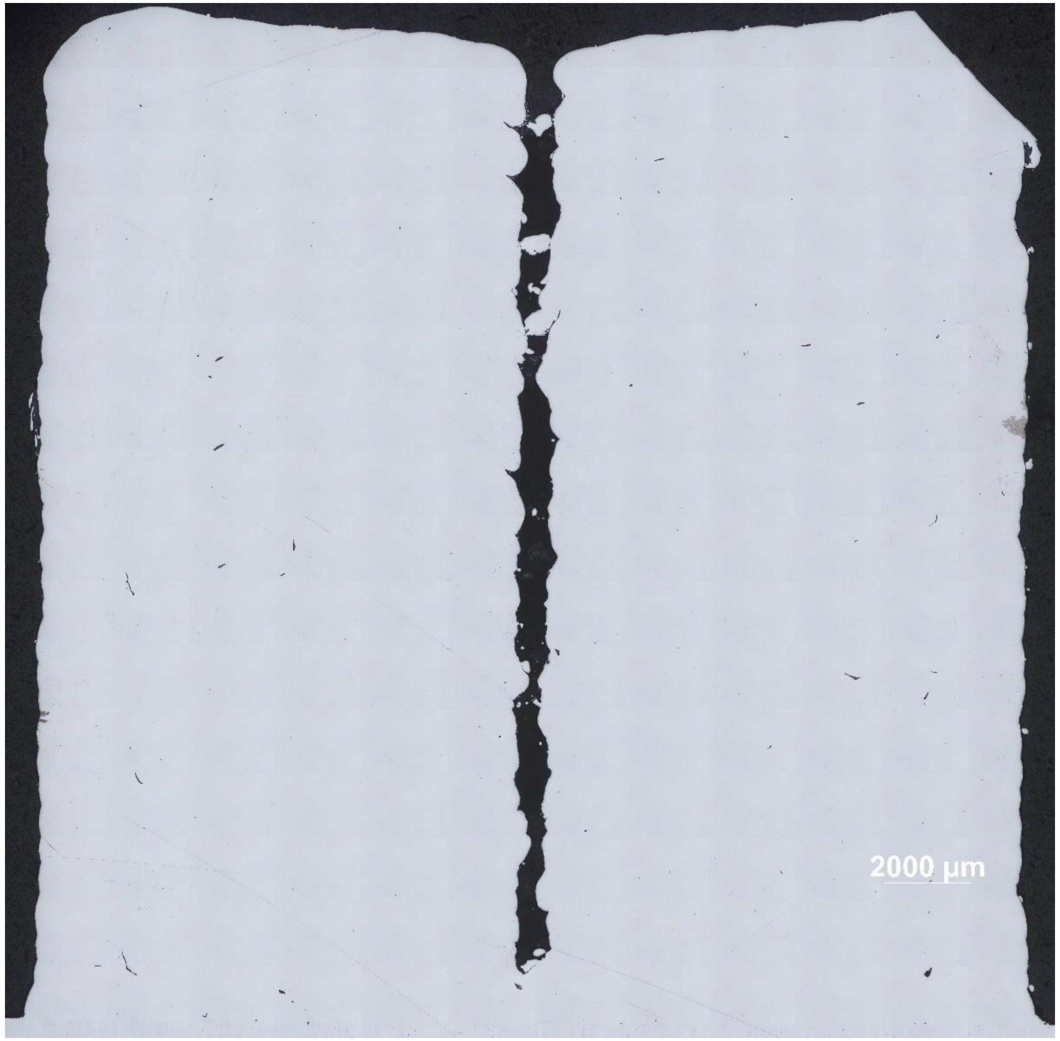


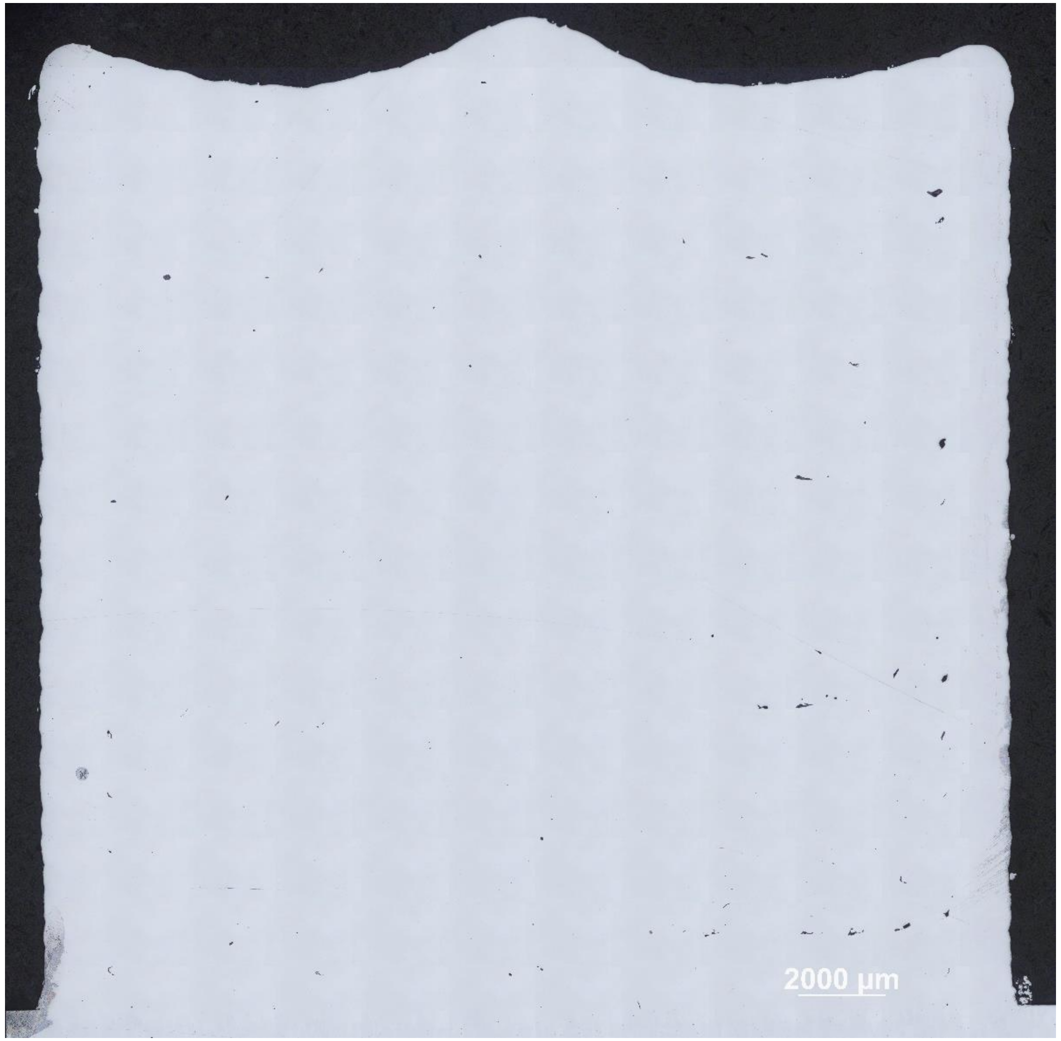
3_4_Spiral



3_6_Spiral



4_4_Spiral



4_6_Spiral

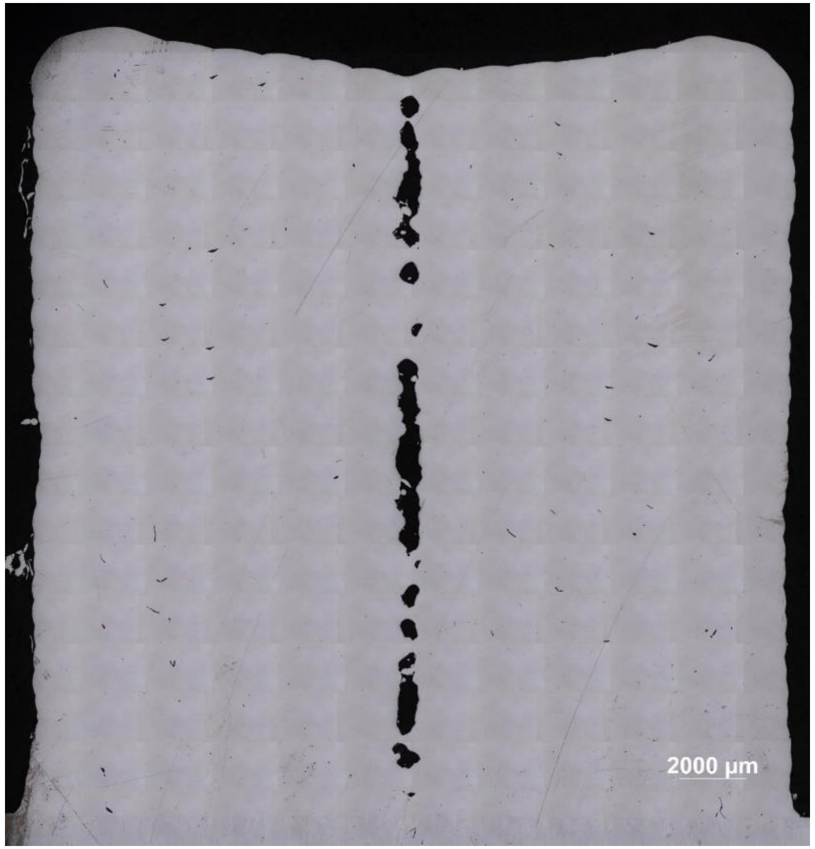
Results – porosity

Sample	Porosity [%]
1_6_ZigZag	0,066
2_6_ZigZag	0,081
3_6_Spiral	0,111
4_6_Spiral	0,067
1_4_ZigZag	0,1
2_4_ZigZag	0,024
3_4_Spiral	1,418
4_4_Spiral	2,483

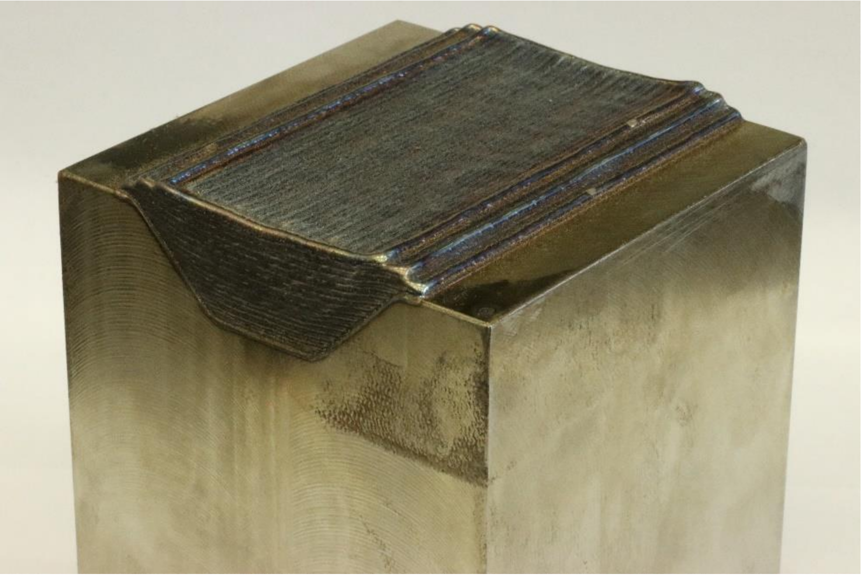
Deposited samples

Sample	Porosity [%]
1_YZ.jpg	0,061
1_XZ.jpg	0,044
2_XZ.jpg	0,141
2_YZ.jpg	0,028

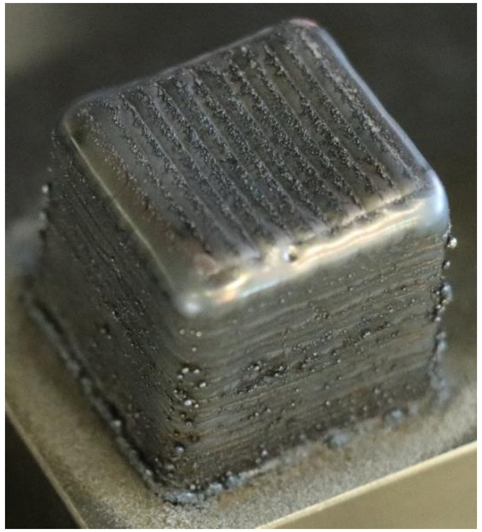
Repair of defect



Conclusions



- Material properties are in good agreement with non-deposited material
- Based on the obtained data, the combination of SDM 1600 and ZigZag strategy results in:
    - ❑ The lowest porosity
    - ❑ The highest hardness
    - ❑ Lower grain size



Future plans

- Advanced material testing
- Comparison between Powder Bed Fusion and Direct Energy Deposition printed samples
- FEM model
- Printing a component for nuclear powerplant
- Qualify pathways for specific printing method and material, which would result in establishing a standards

Acknowledgment

Czech Technical University in Prague

FJFI

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Special thanks to my colleagues: Martin Ševeček, Antonín Prantl, Josef Hodek, Michal Brázda, Pavel Podaný and the staff of the COMTES fht a.s.

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