Additive Manufacturing

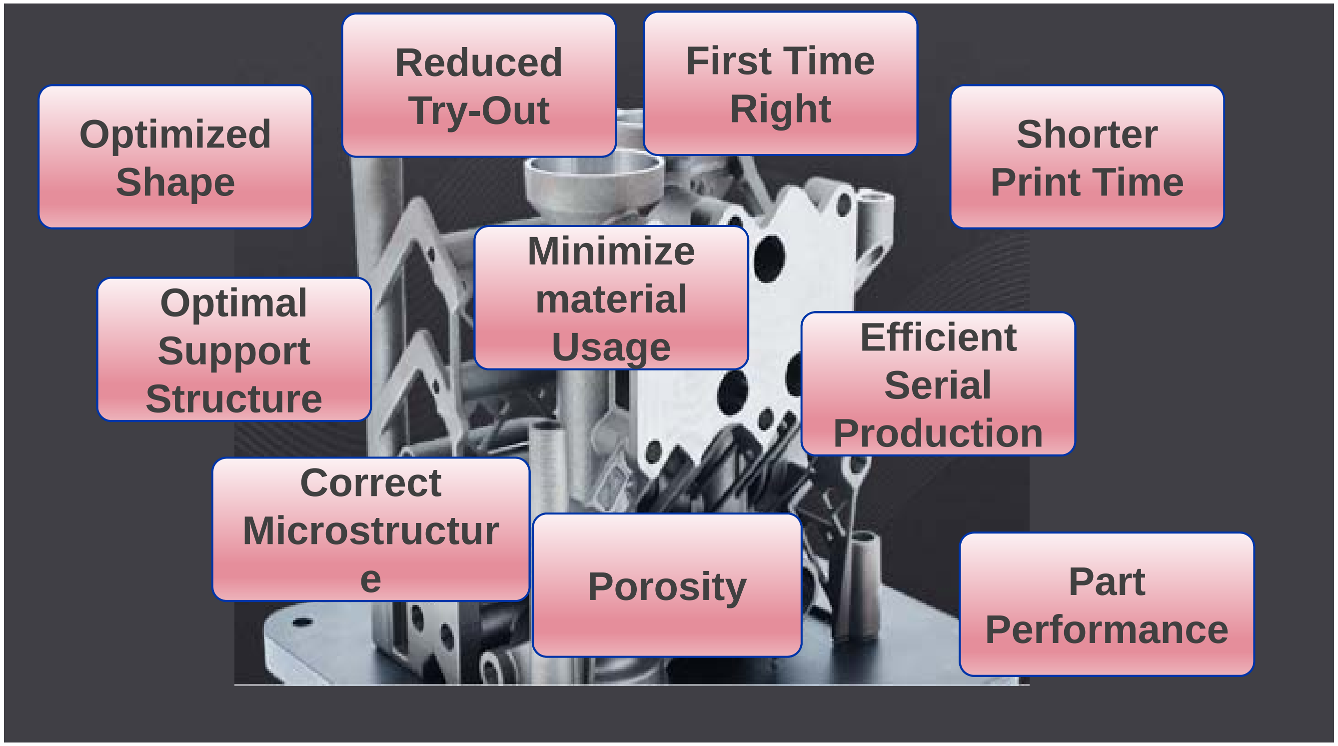
From Trial and Error to a Standard Industrial Process

Topics

- Introduction
- Process Simulation of AM
  - Metals
  - Polymers and Composites
- Conclusion

Additive Manufacturing (AM) opens up amazing possibilities

It also comes with its own, unique challenges



Main challenges

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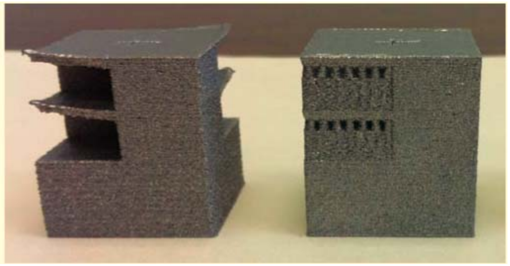
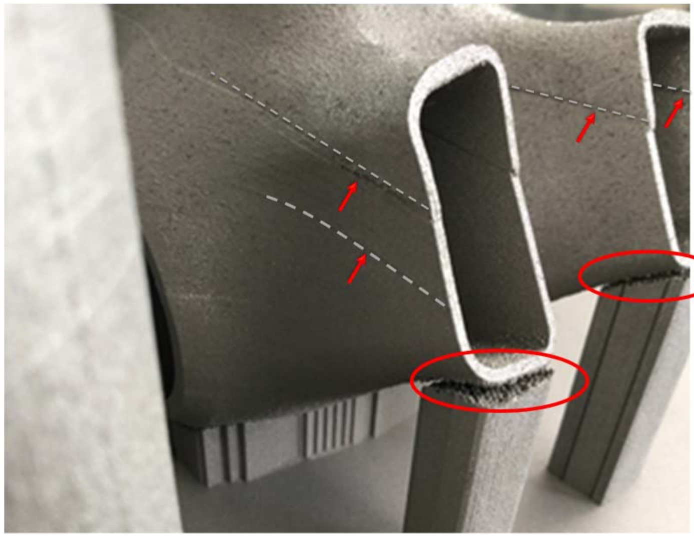
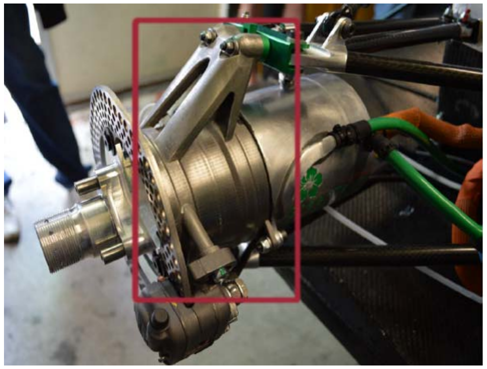
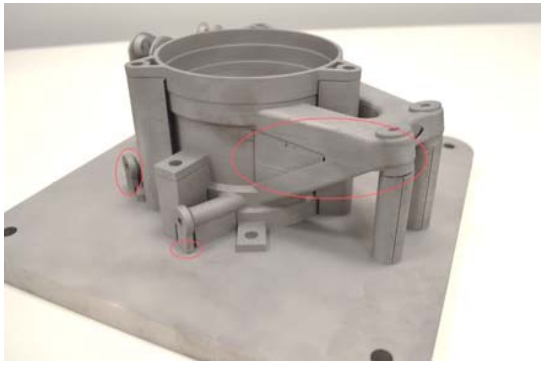
- **Distortion**
  - Part out of tolerances
  - Collision with powder scraper
- **Residual Stresses**
  - Part of support failure
- **Quality**
  - Porosity
  - Microstructure





Additive Manufacturing (AM) Process





Design → Build → Inspect

With manufacturing simulation

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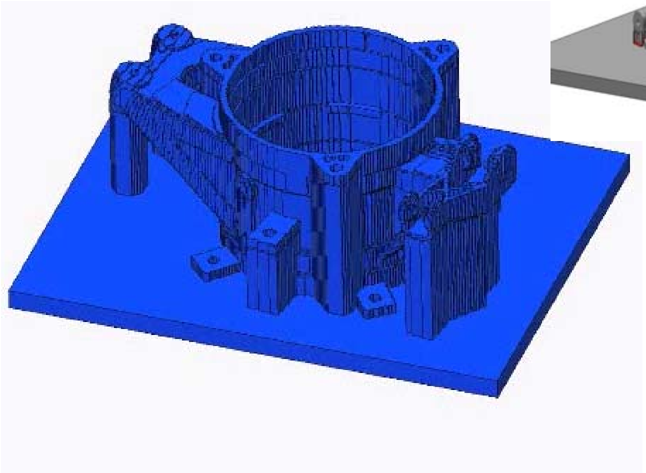

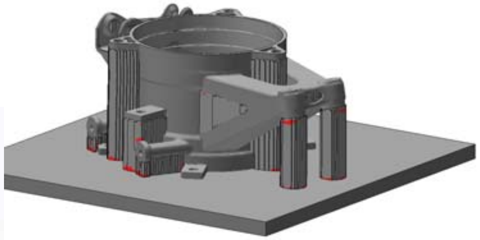

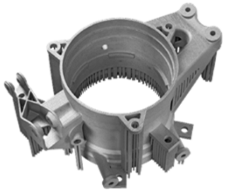

Design → Manufacturing Simulation → Build → Inspect

AM Process Simulation

Analysis scales

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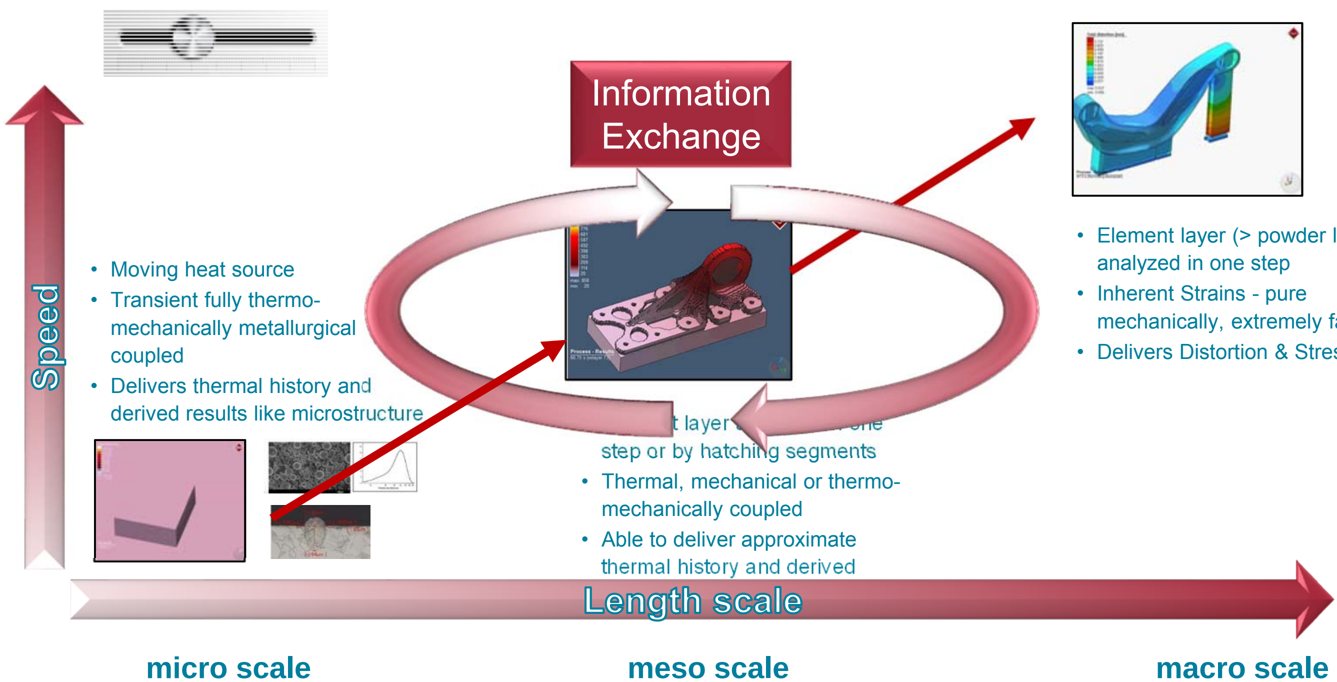


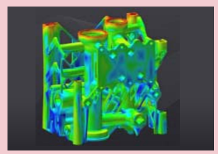
Macro scale

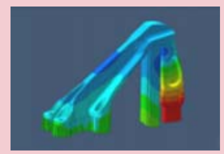
IMPLEMENTATION

- Voxel technique
- Inherent strain
- Layer based

RESULTS

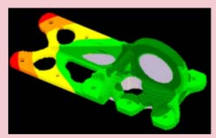
- Part distortion
- Residual stress





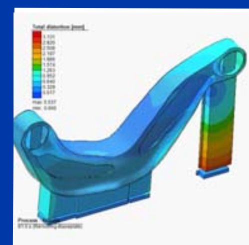
BENEFIT

- Extremely fast
- Simple calibration



CPU Time

5 minutes



Voxel technique with solid fraction

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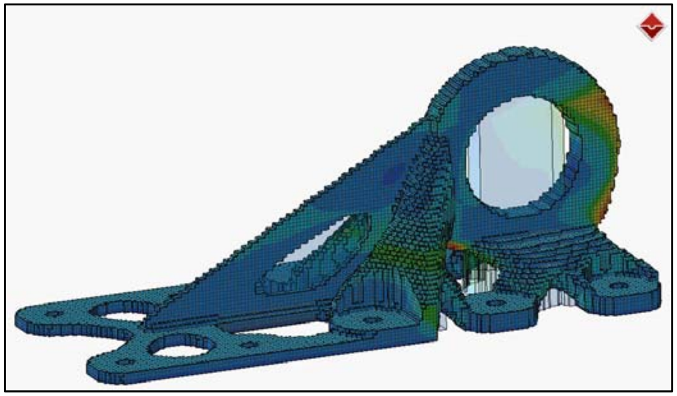
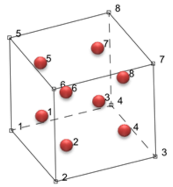
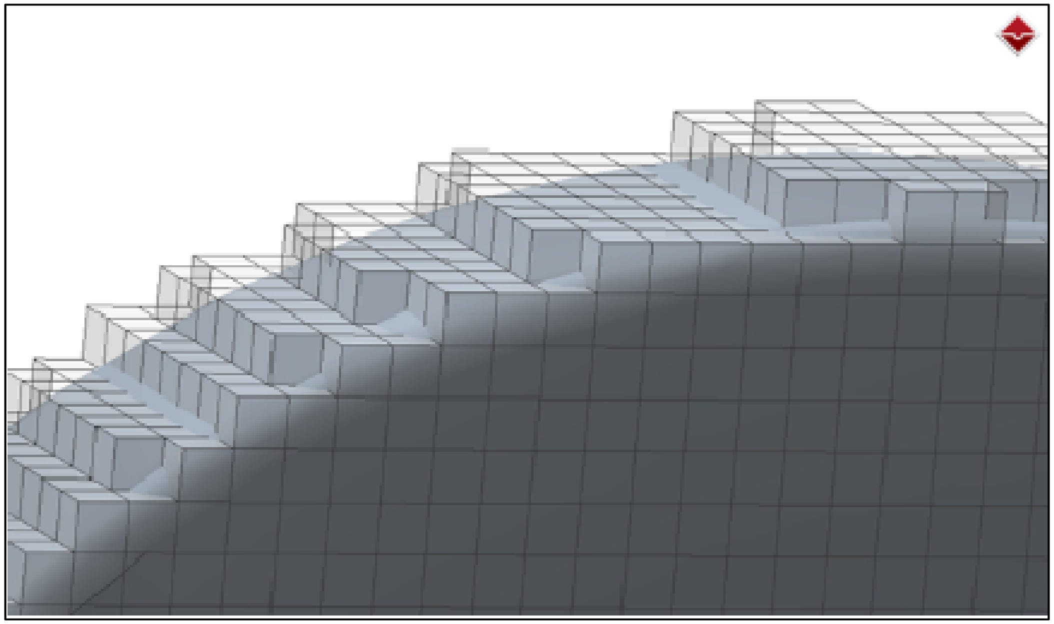






Inherent strain

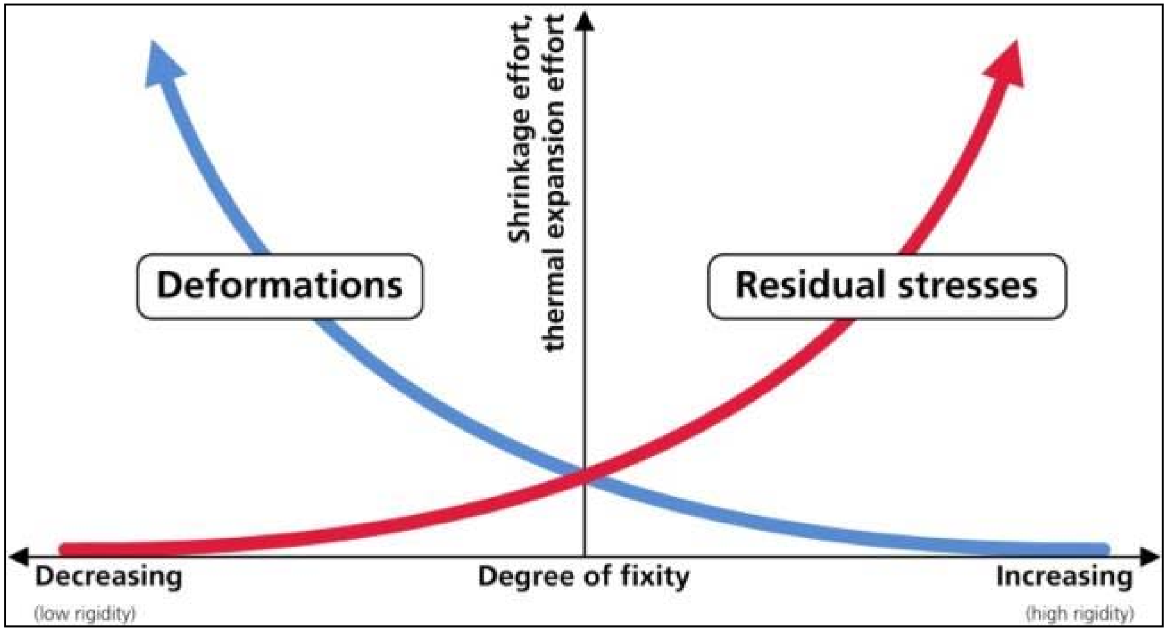
Comprise

- Plastic strains
- Thermal strains
- Creep strains
- Phase transformation strains

Reflect

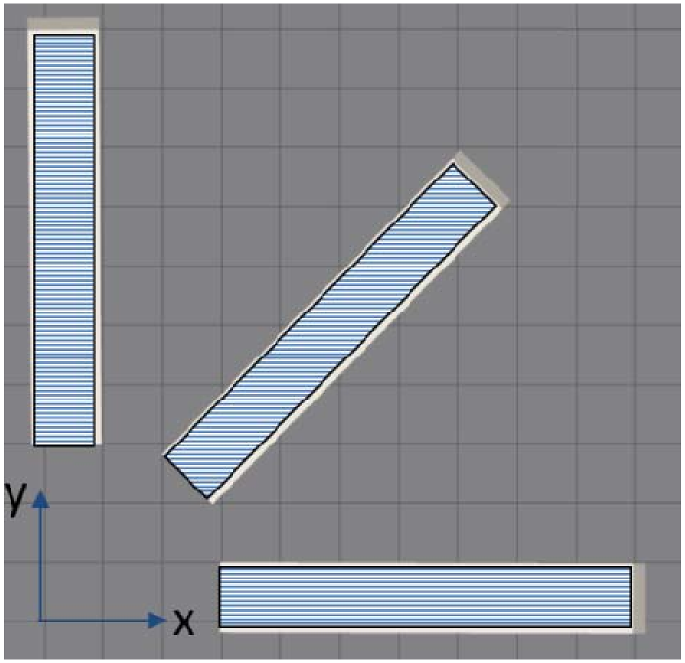
- Material
- Manufacturing parameters
- (Individual) machine

Are orthotropic by nature



Calibration of inherent strain by simple cantilever build

Step 1: Build cantilevers ➔Cut ➔Measure tip displacement



Calibration of inherent strain by simple cantilever build

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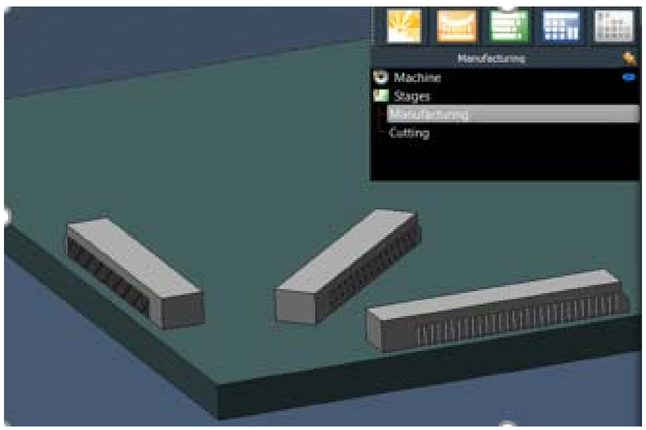
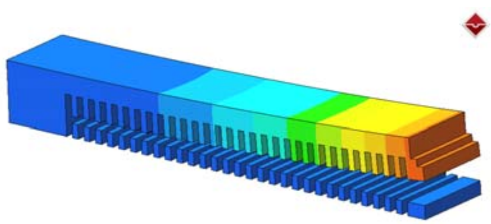
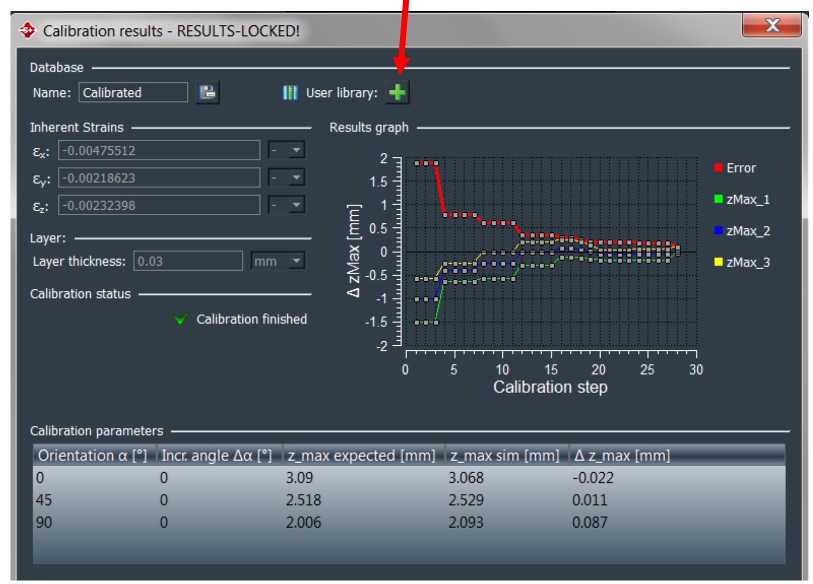
Step 2: Automatic calibration

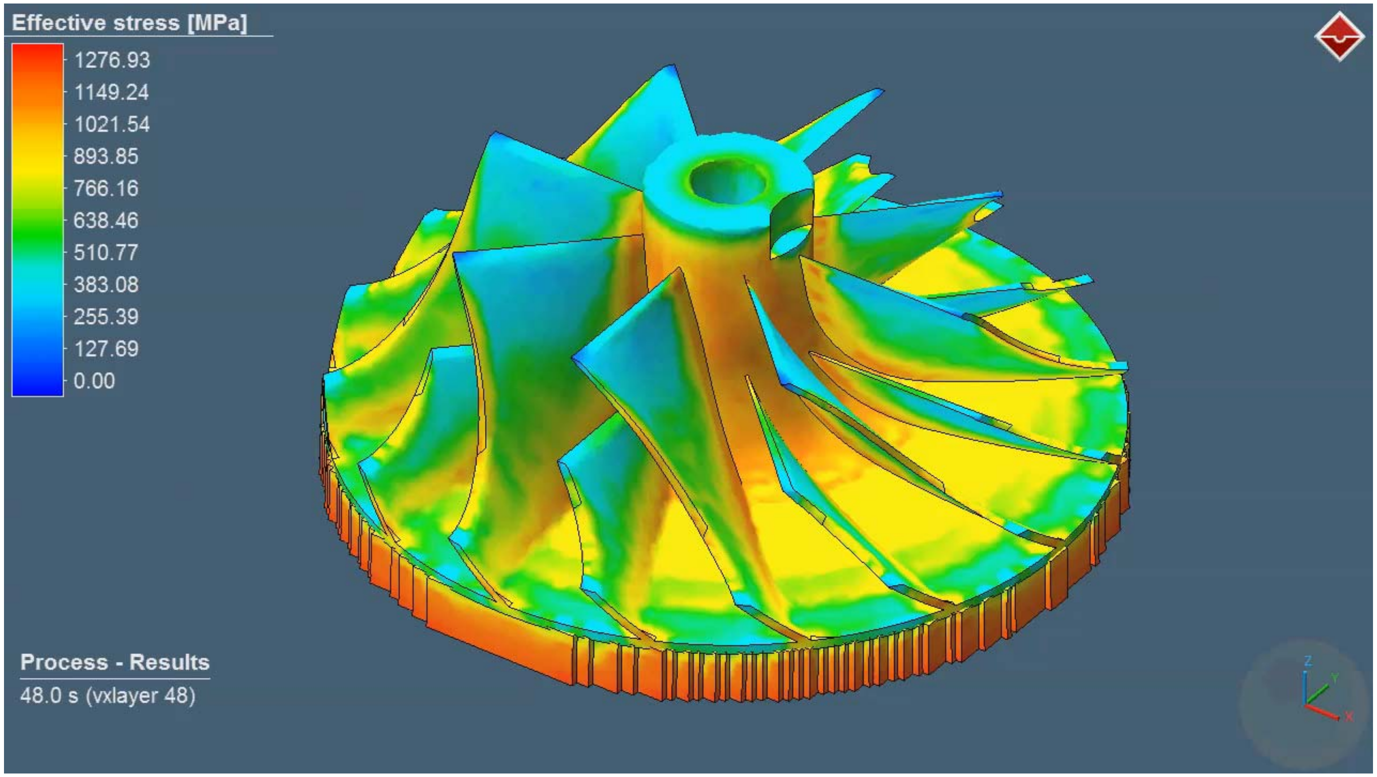




Store in database



Once calibrated, run simulations on actual parts



Validation Examples

Validation example

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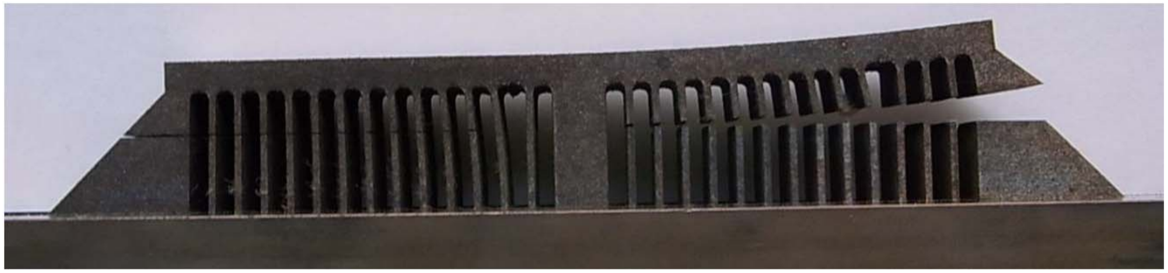

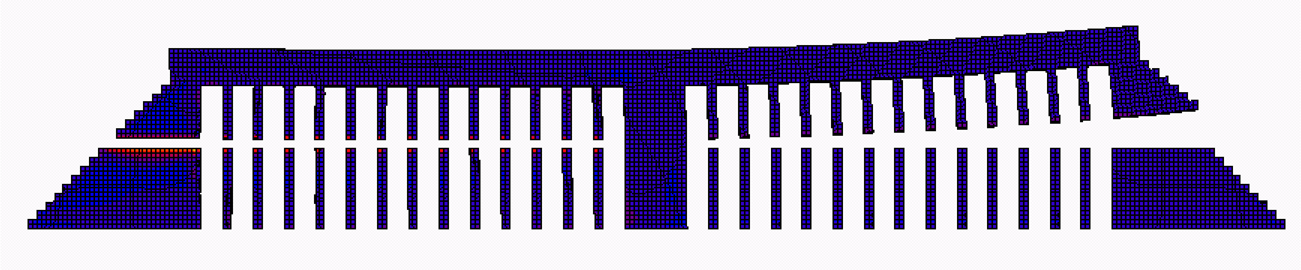

Validation example

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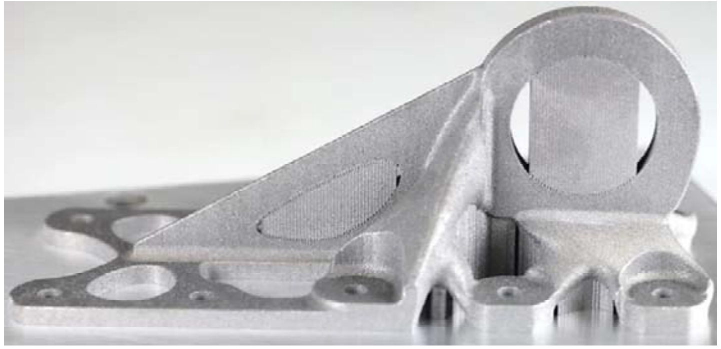
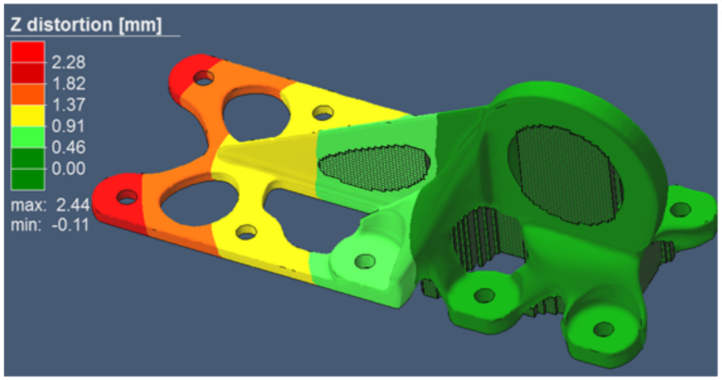
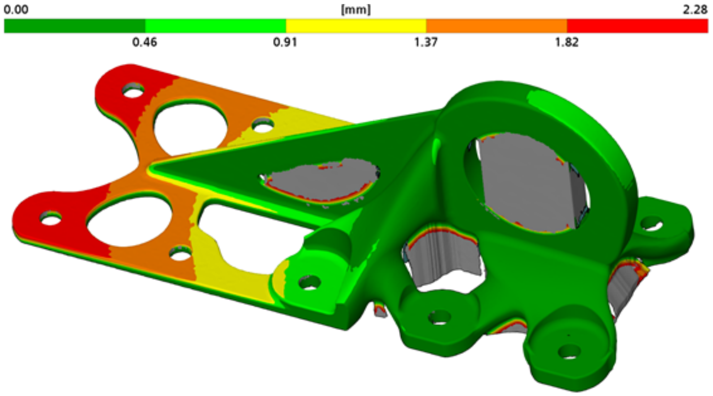




Simulation



Actual Part

Validation example

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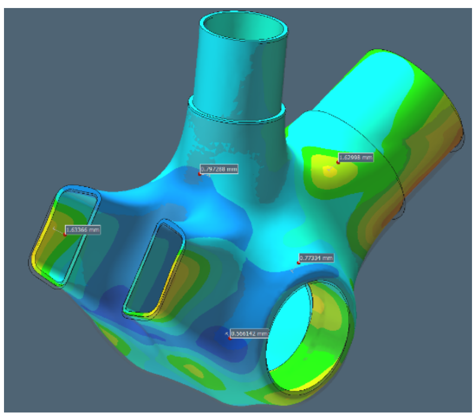
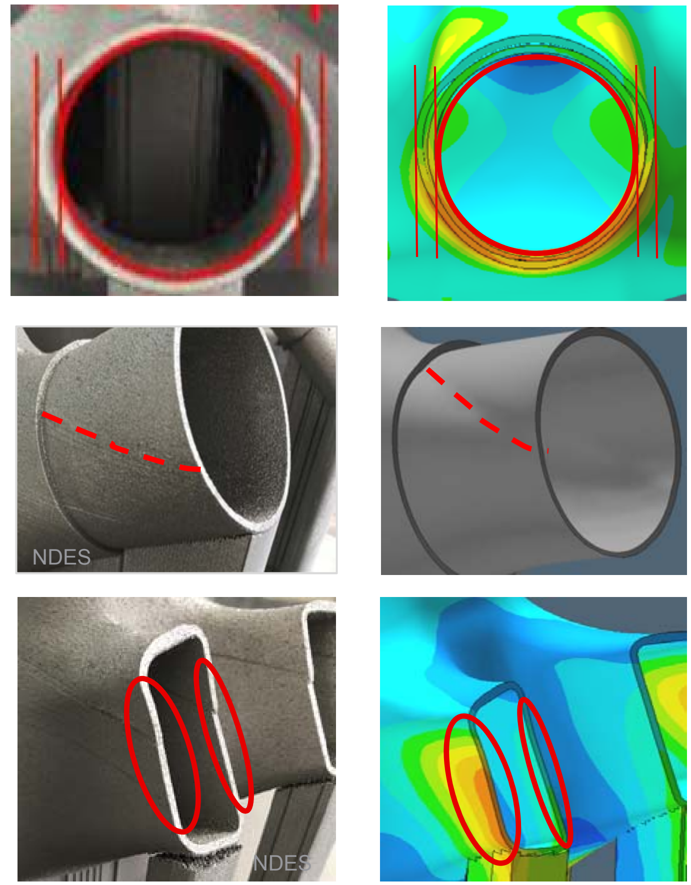
NTT DATA





Validation example

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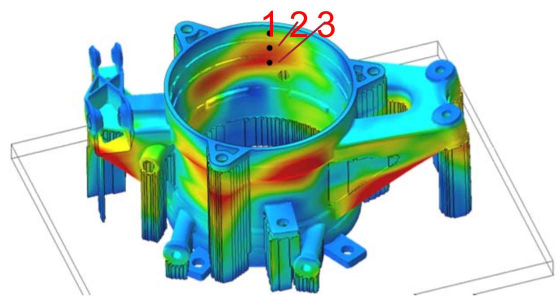

Distortions

Point	Simulation (mm)	Experiment (mm)
1	0.3539	0.3532
2	0.5527	0.5517
3	0.5931	0.5920

Cross Section Contour Distortion

Simulation

Experiment

Scaled displacement = 10x

Validation example

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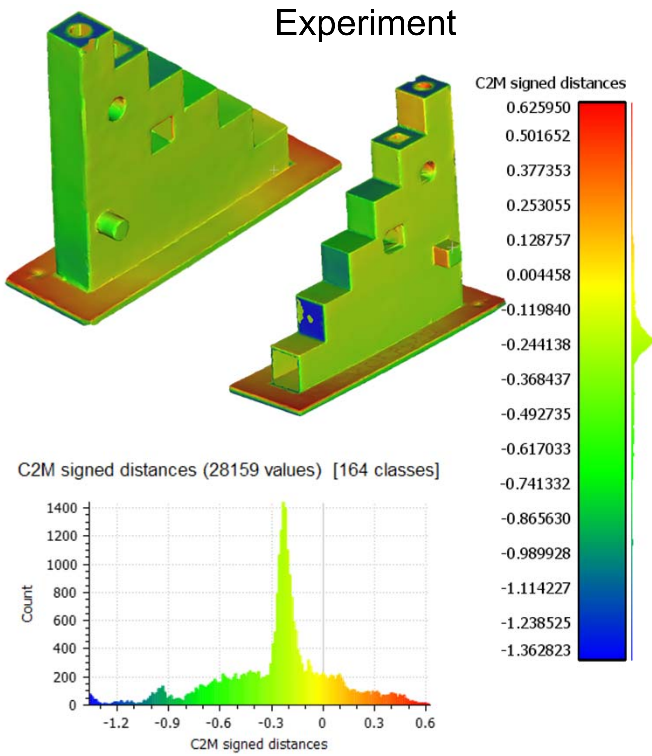
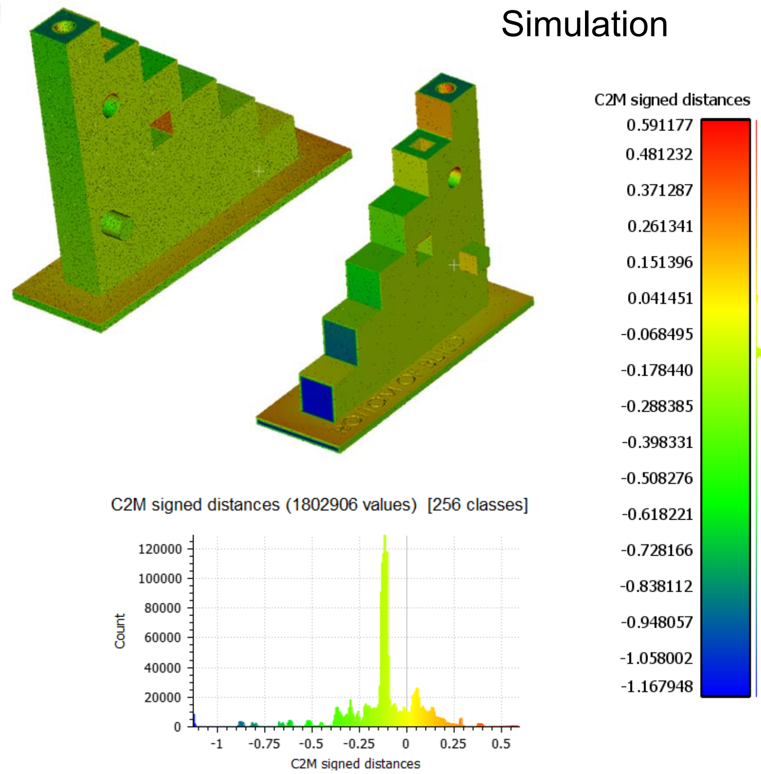
Sinterline® powder *(Glass beads reinforced polyamide)*

Experiment

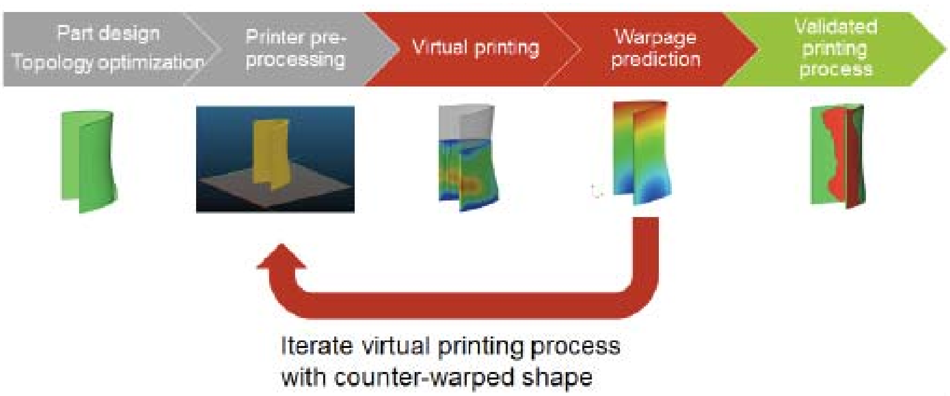


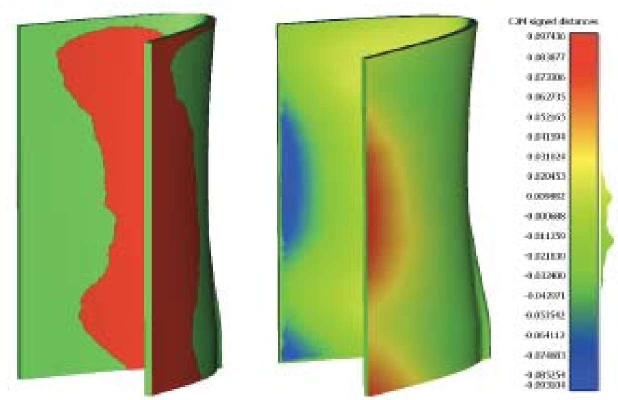
Simulation



Validation example

Stratasys – Composite Tooling

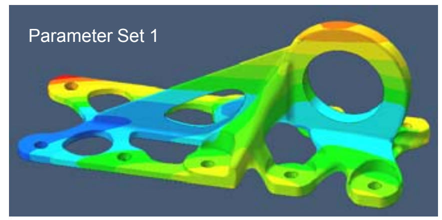


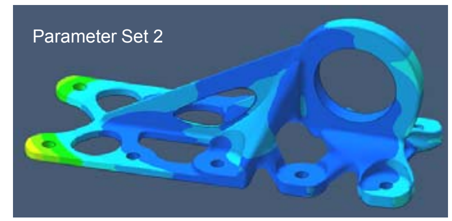


Warpage prediction after geometry compensation in Digimat-AM. Left: superposition of the as-printed (red) and as-design (green) parts. Right: RMS signed distance. Maximum deviation is below 0.1 mm.

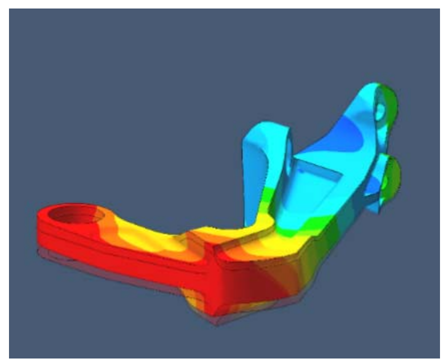
Virtually explore the influence of:

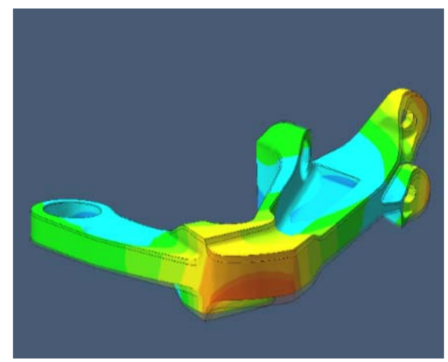
- Manufacturing parameters & materials





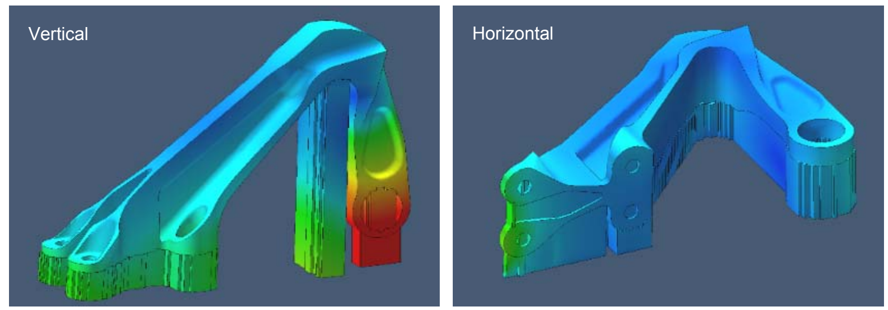
- Cutting direction & supports removal sequence



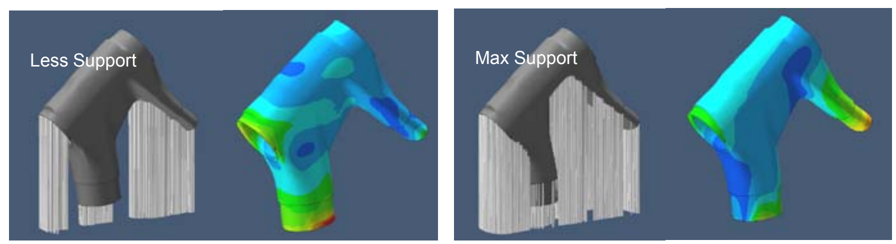


Virtually explore the influence of:

- Build orientation

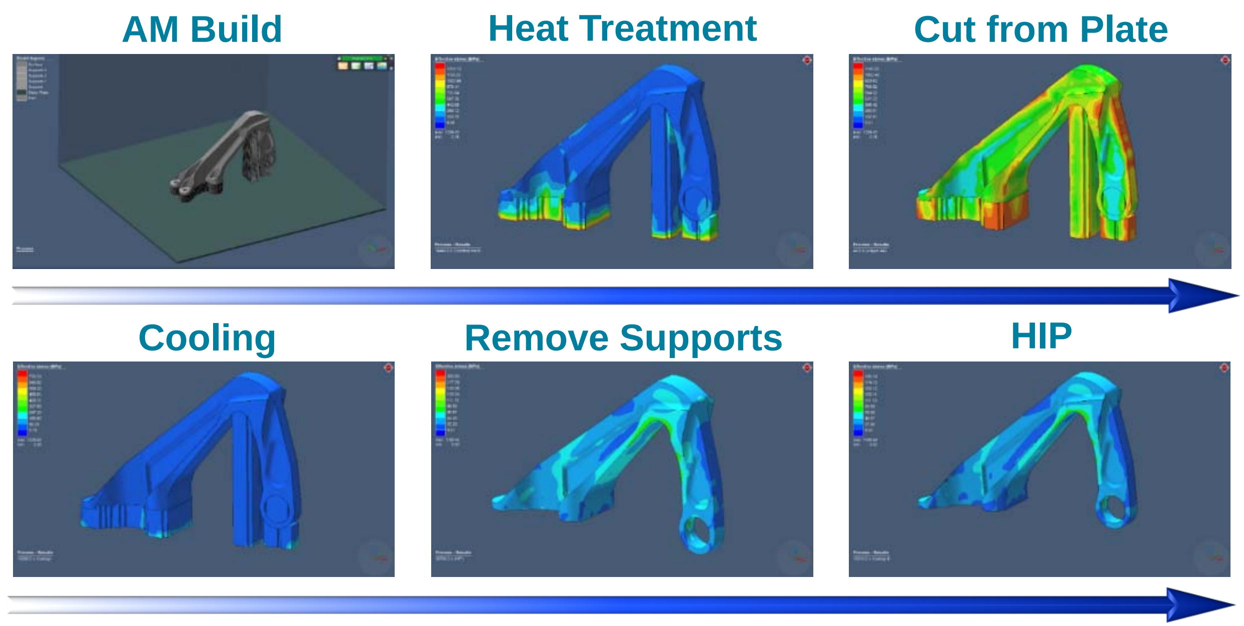


- Support structure configuration



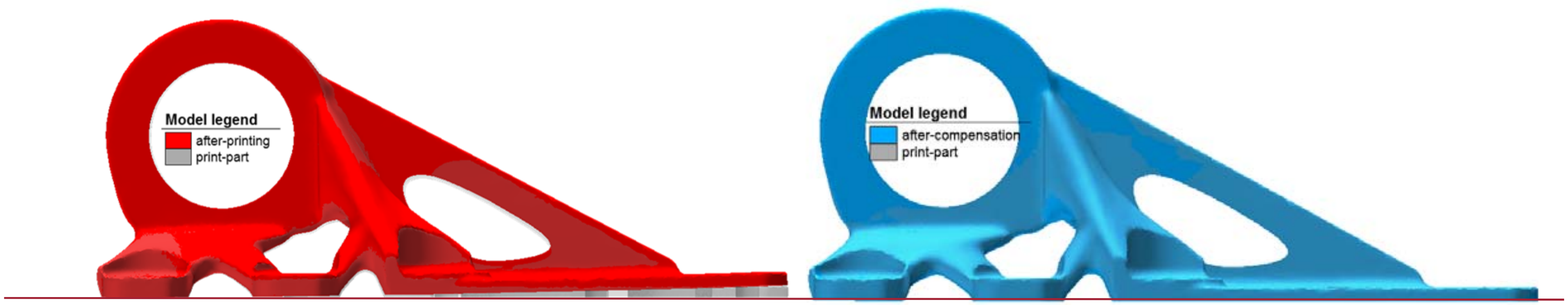
Virtually explore the influence of:

- Process chain



Virtually explore the influence of:

- Optimal compensated shape



Polymers Example

Consideration of polymer parts

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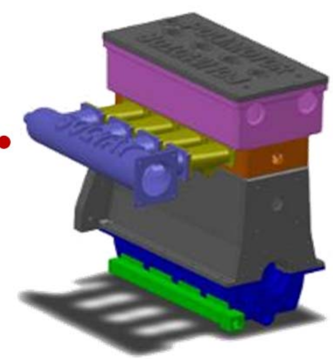
- Additive Layer Manufacturing
  - FFF/SLS
    - Material Engineering
      - Mechanical
      - Thermal
      - Electric
    - Process Simulation
      - Warpage
      - Residual Stress
      - Porosity
    - Part Performance
      - Stiffness
      - Failure
        - Print Direction
        - Reinforcement

Sinterline® plenum chamber; Powder Bed Fusion (SLS)

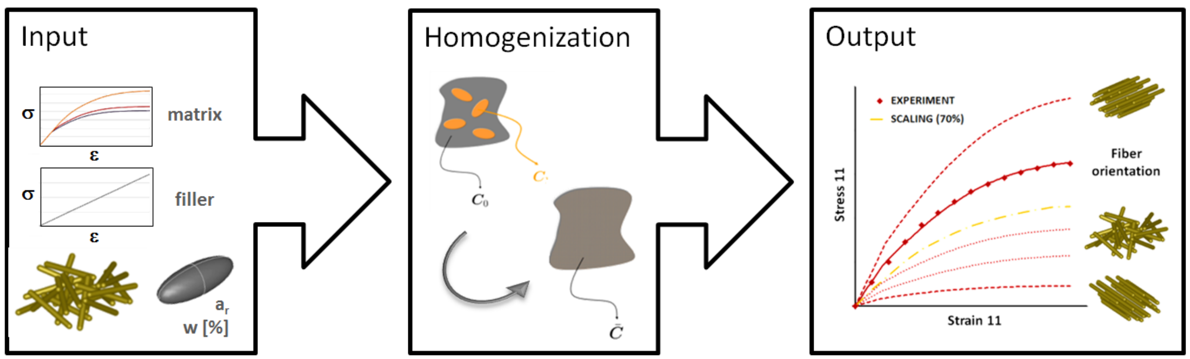
- Plenum is part of the Polimotor project (all plastics engine)
- Long-term goals:
  - Introducing plastic parts in future automotive engines
  - Highlighting trailblazing polymer technologies and their potential
- Challenge: the additively manufactured plenum must demonstrated that:
  - It can withstand the working loads
  - It can perform with same reliability as its injection molded counterpart

3D printed plenum chamber

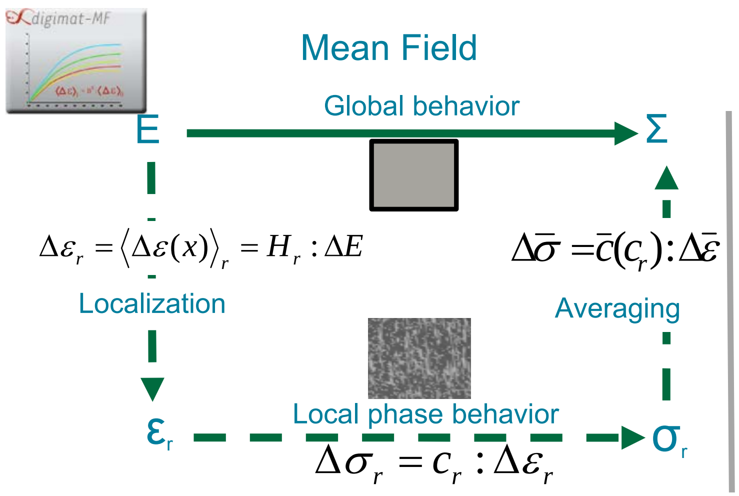


Polimotor 2

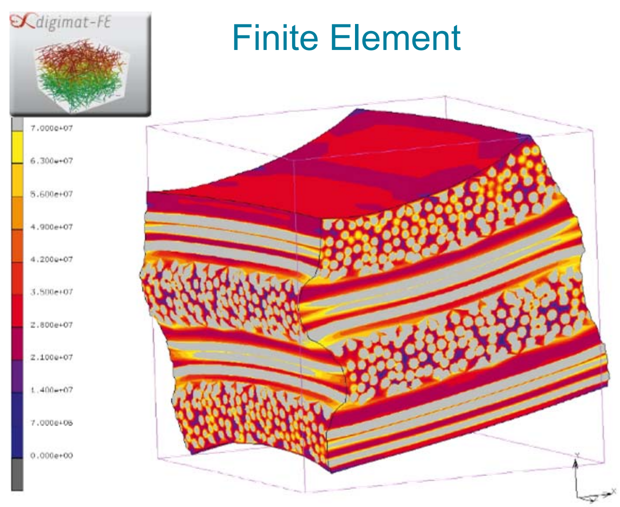
Material characterization with nonlinear micro-mechanics



Mean Field



Finite Element



Sinterline® material characterization

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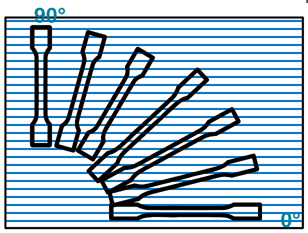
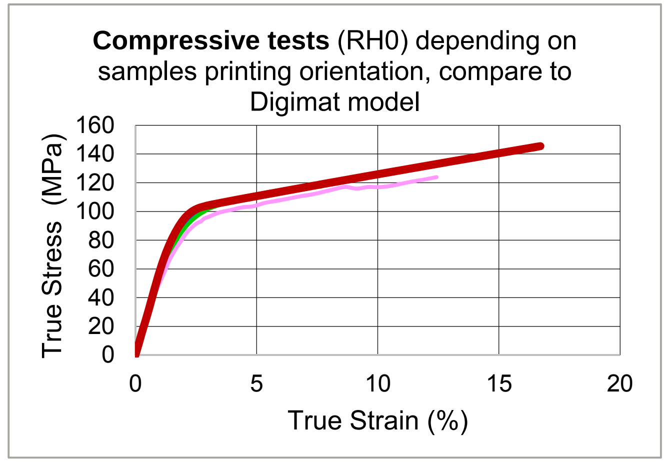
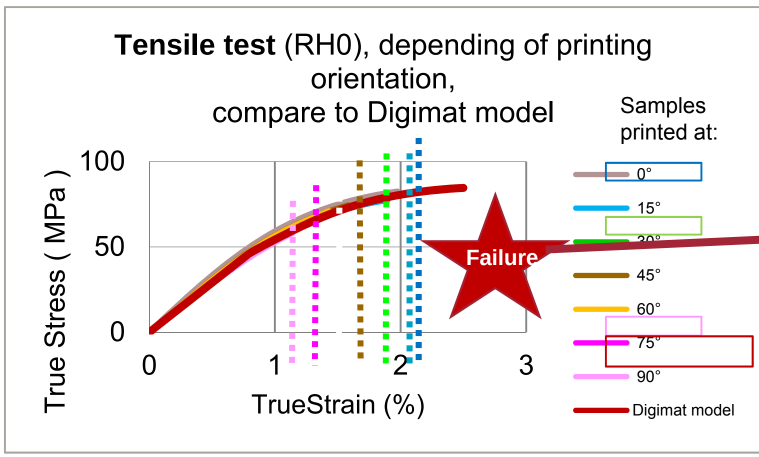
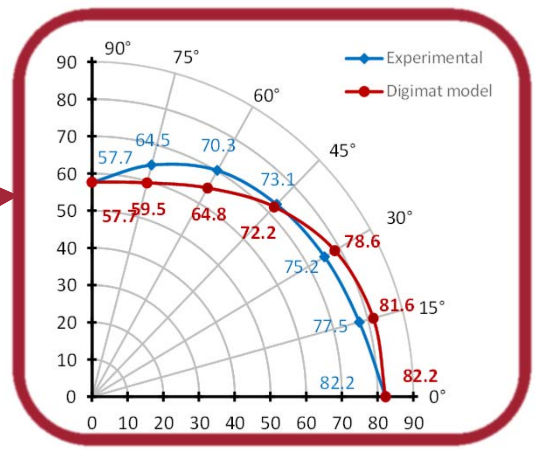
SOLVAY

Stress-Strain curves and Failure dependent on printing orientation









Simulate AM build process

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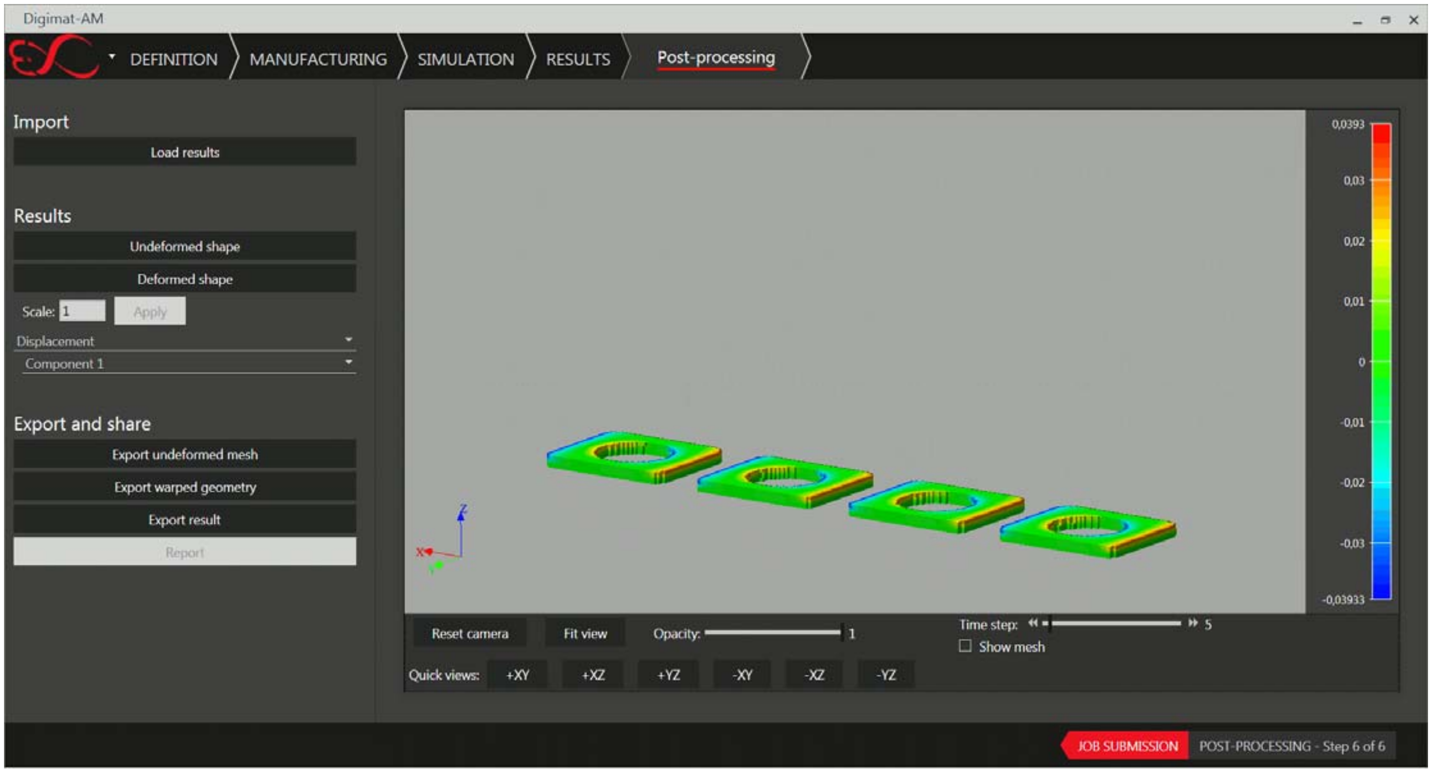
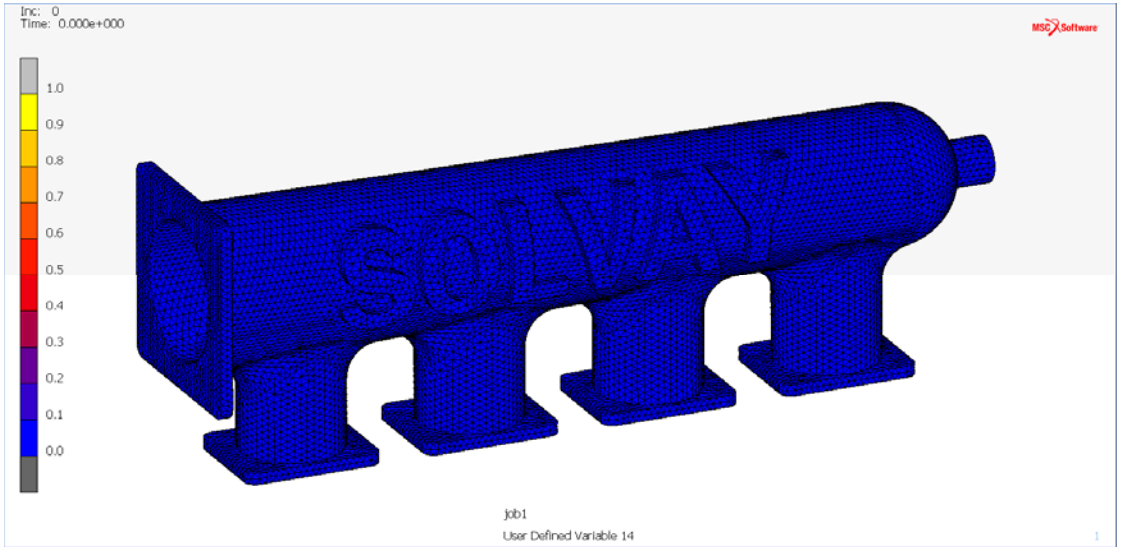


Performance analysis

SOLVAY

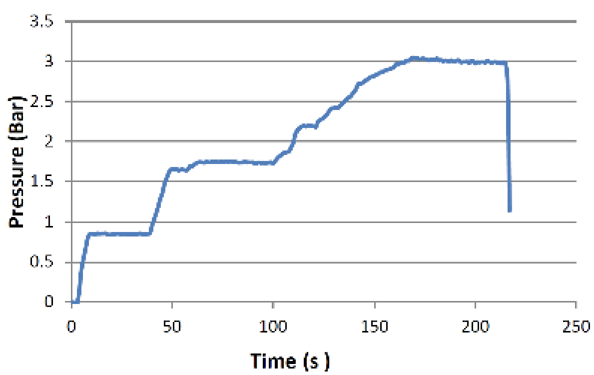
Pressure at failure for different build orientations

• Build in width direction	12.8 bars
• Build in height direction	12.0 bars
• Build in length direction	8.1 bars
• Build in angled orientation	9.1 bars



Experimental testing

- Method
  - Pressure increase by steps up to 6 bars positive air pressure inside the plenum
  - Pressure release to ambient pressure after 1 hour at 100 degrees C
- Conclusion
  - No burst of the part during test validation of part strength
  - Test successful



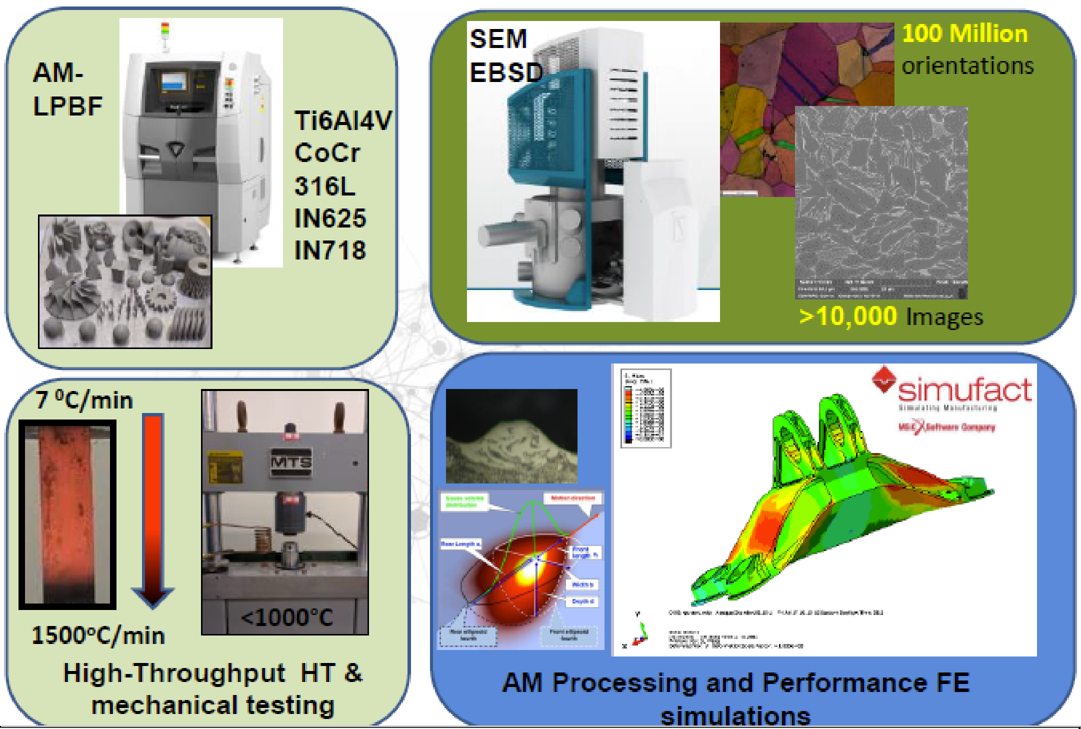
Experimental pressure profile

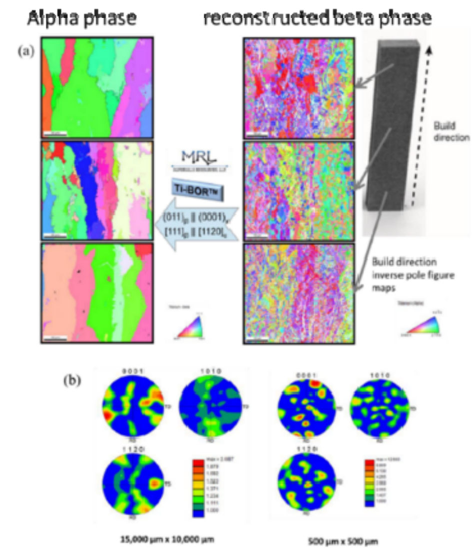
Experimental set up

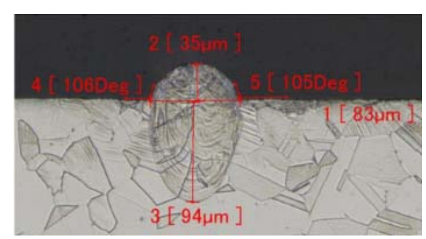
Metal AM Simulation - Prediction of microstructure

MRL
MATERIALS RESOURCES, LLC

Transient simulation with microstructure in cooperation with MRL







simufact

AM ICME platform for data analytics, material modeling, and FEM simulations

Conclusion

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- You can design amazing structures – simulation is a must to reliably print them

- Simulation is required for:
  - the whole process (build, cut, heat-treat),
  - the complete chain (material, process, performance)
  - At different scales (macro, meso, micro)

- New simulation tools are available and are advancing rapidly