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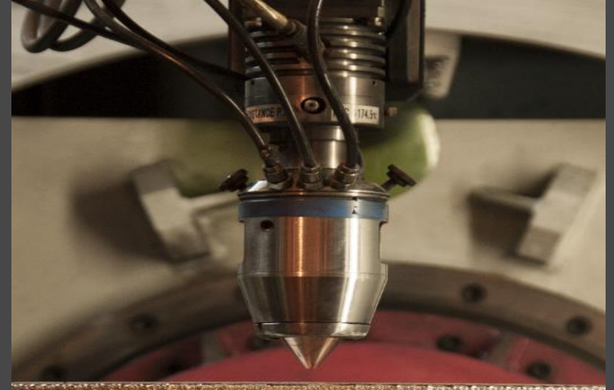
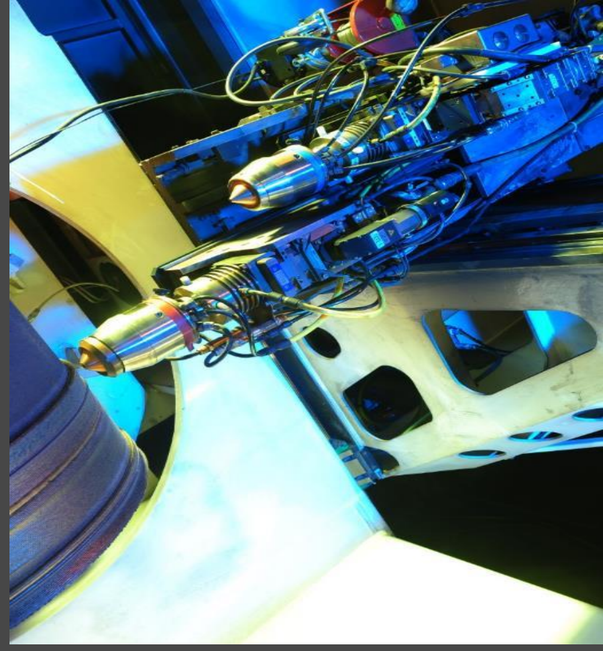
Process Simulation of Directed Energy Deposition process using COMSOL Multiphysics®

Thermo-mechanical Simulation for DED

- DED
- Why simulation?
- Challenge!
- Project Goals!





Directed Energy Deposition (DED)

Part defects

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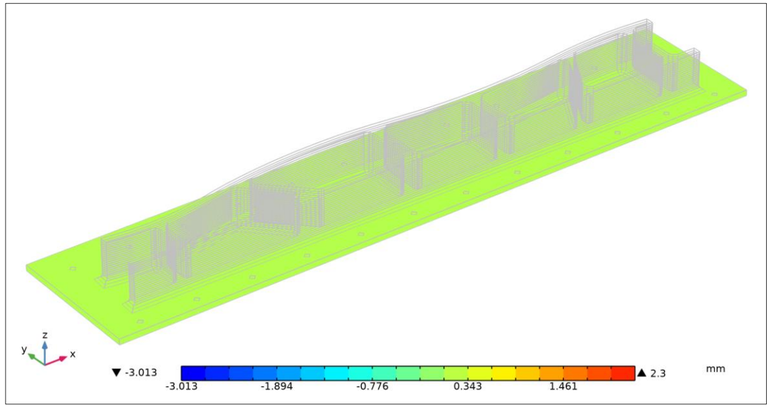
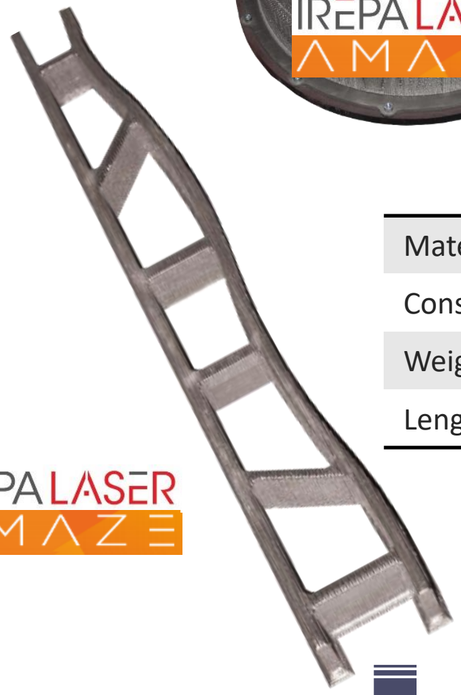


Digital test

What if!

Material	Ti-6Al-4V
Construction	Total : 155h
Weight	71kg
Diameter	680 mm



Material	Ti-6Al-4V
Construction	Total : 33h
Weight	14,2kg
Length	1070 mm

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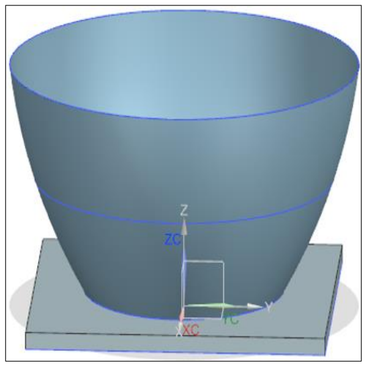
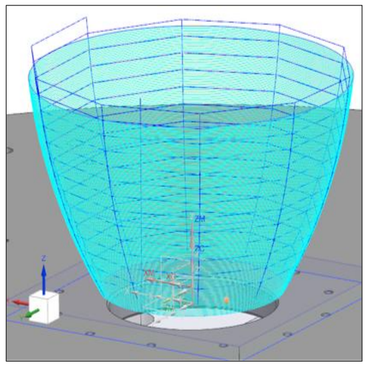
Why simulation?

Digital Chain: Current missing link in industry for large-part fabrication



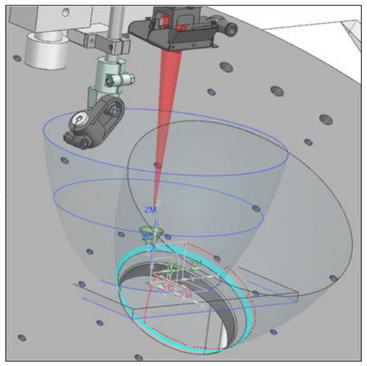
CAD DESIGN & OPERATIONS

- Perform & finalize part design
- Decompose part geometry
- Different operations on bodies



CAM PROGRAMMING

- Specify additive material
- Apply deposition strategies
- Finish & obtain deposition path



MACHINE SIMULATION

- Machine simulation
- Collisions verification
- Machine & path verification

PROCESS PARAMETERS OPTIMIZATION

- Trial & error approach
- Lots of time & money
- Cannot predict deformation

PART FABRICATION

- Transfer CAM to DED machine
- Part fabrication
- Process data optimization

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Challenge!

Computation time

V. Nain (PhD 2019-22)

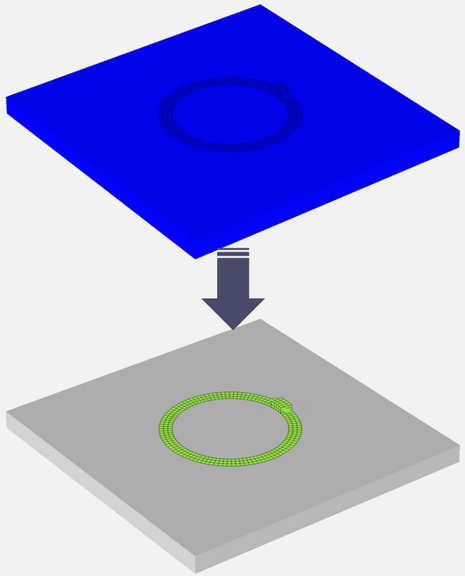
[1] [2] [3] [4]

Model	Computation speed	Computation accuracy	Large-part simulation
Meso scale	✗	✓	✗
FH	✓	?	✓
SFH	✓	✓	?
Inherent-strain	✓	✗	✓

HEXAGON MSC Software is Hexagon

Ansys

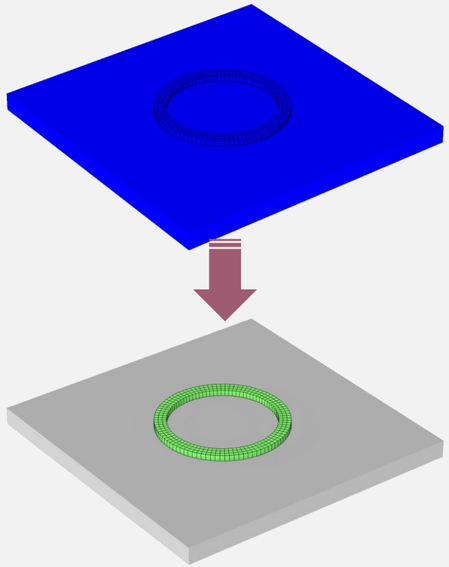
Meso-scale



Simulates laser movement ✓
Simulates melt-pool scale

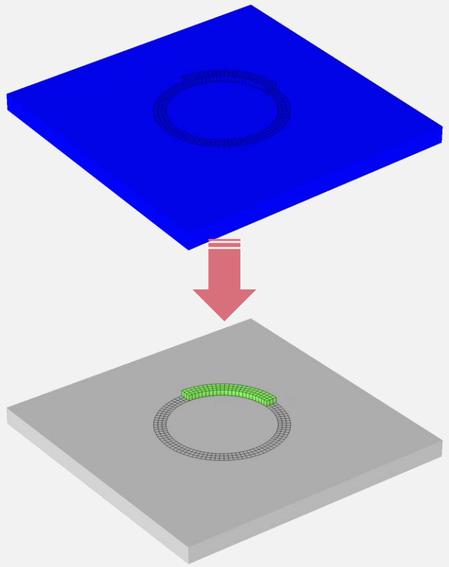
Part-scale

Flash Heating (FH)



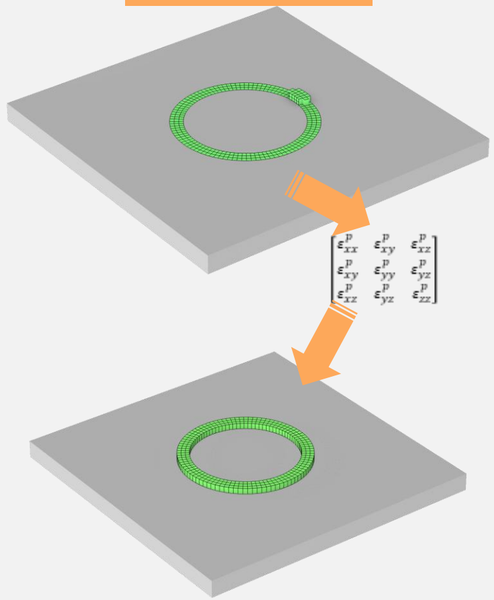
Do not simulate laser movement ✗
Simulates layer scale

Sequential FH (SFH)



Simulates laser movement ✓
Simulates sub-layer scale

Inherent Strain



Meso: Calculate Inherent Strain
Part: Apply Inherent Strain

AS OF TODAY: THE MODELING STRATEGY FOR LARGE DED PART IS NOT VALIDATED

COMPUTATION TIME & ACCURACY

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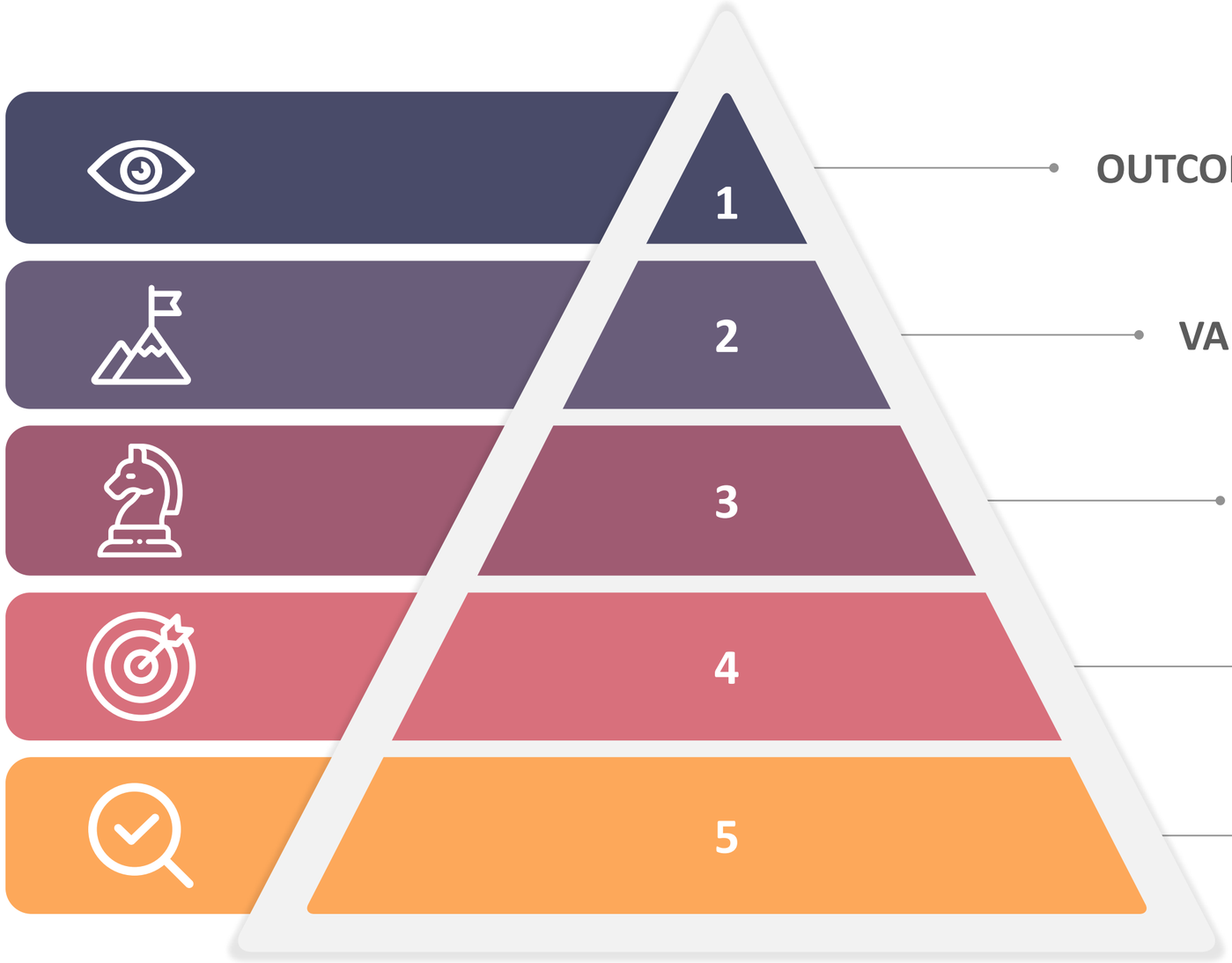
Project Goals!

Digital tool for large-part DED



OUTCOME: PREDICTIVE SIMULATION TOOL FOR LARGE-PART DED

COMSOL

VALIDATE: With experiment data

FOCUS: Computation time reduction

DEVELOP: DED process simulation model

COMSOL

INVESTIGATE: Current modeling methods

COMSOL

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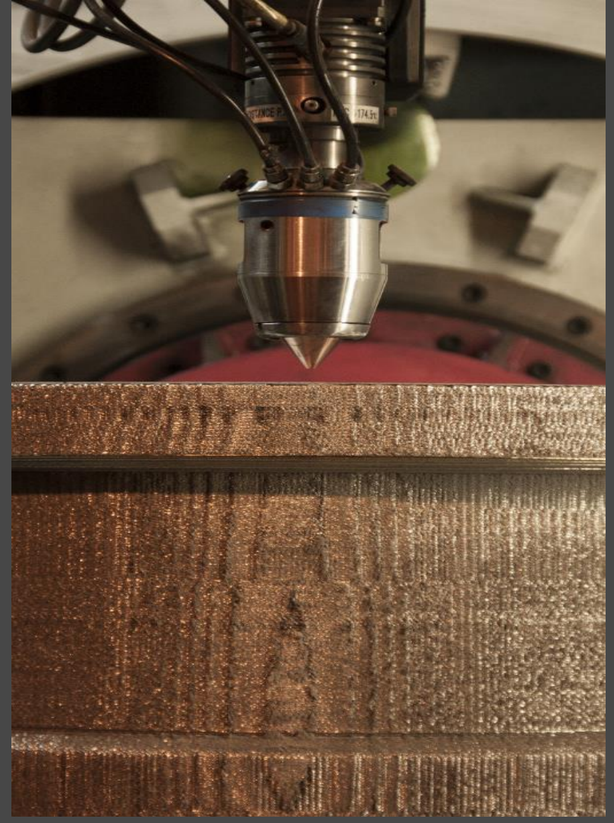
Methods and use of COMSOL Multiphysics®

- Experiment
- Numerical model development
- Numerical model set-up
- Numerical analyses



Experiment

Experiment DOE

LASER

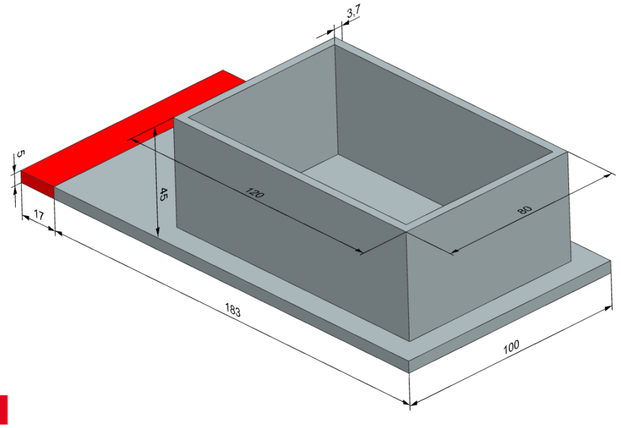
P: 800 W
v_L : 1 m/min
ϕ_L: 2.2 mm

MATERIAL

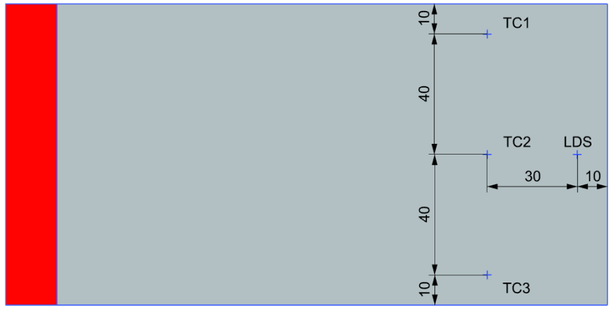
Substrate: S235
Build part: SS 316L

DIMENSIONS

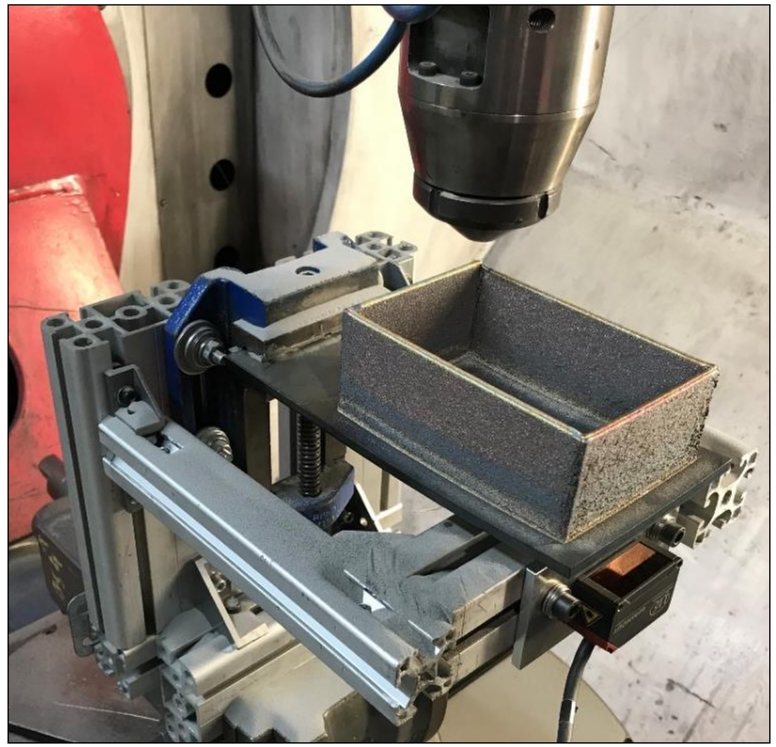
100 layers (2 tracks/layer)
Total weld length: 80 m



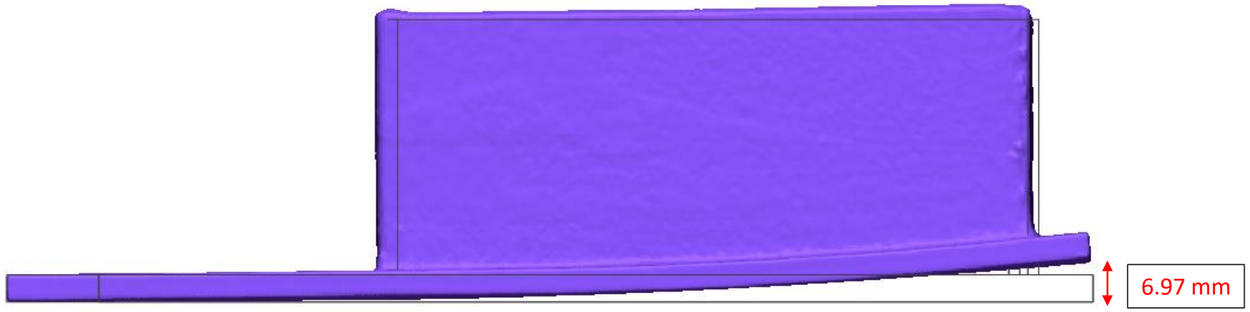
CAD



Sensors location



Experiment



Scan data v/s CAD

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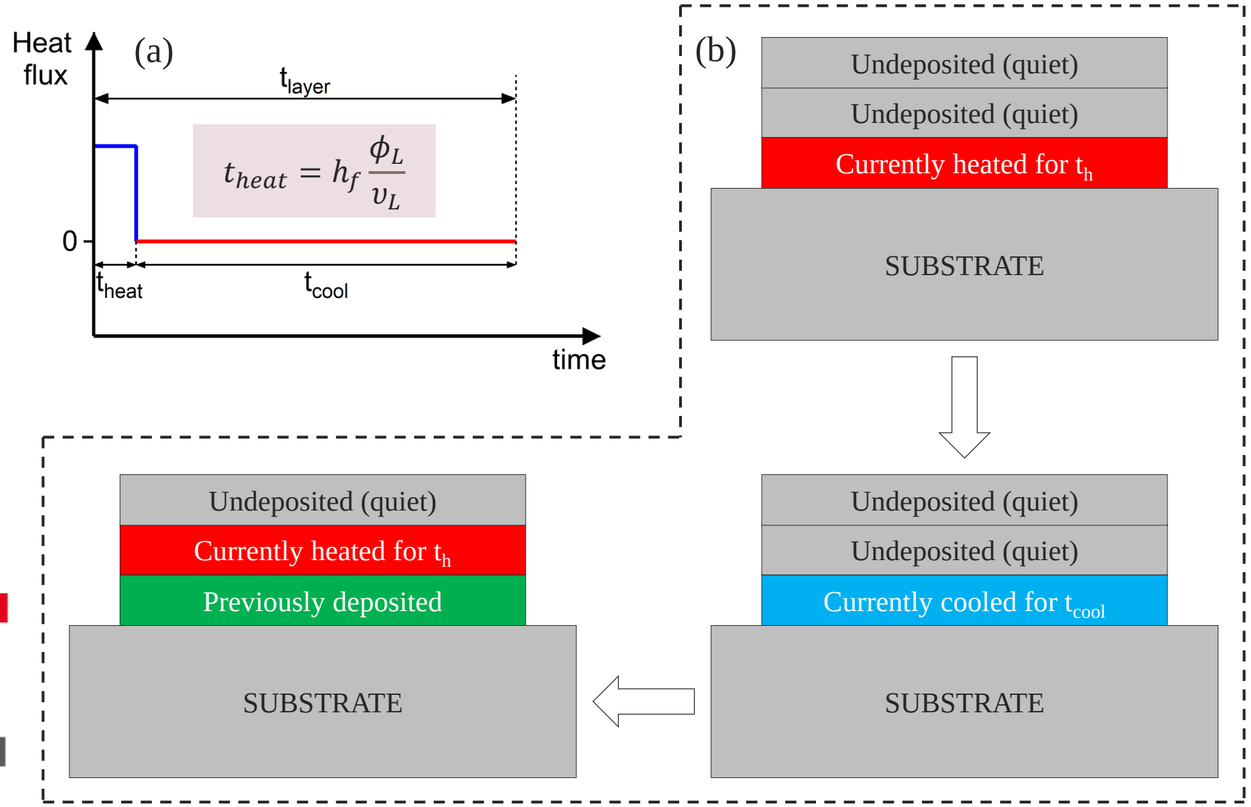
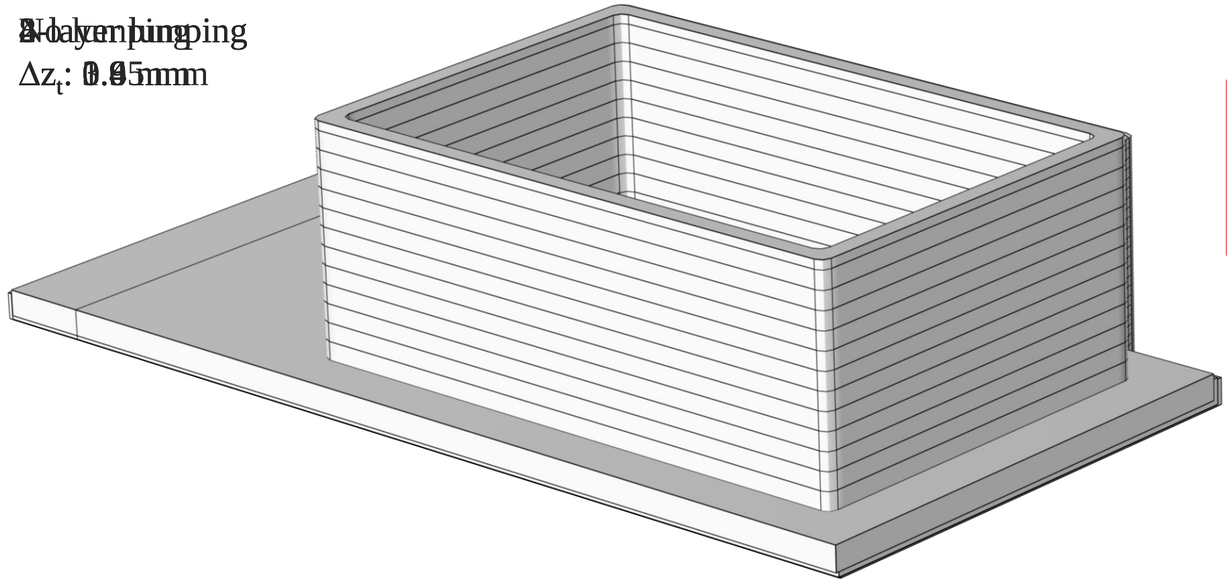
Numerical model development

FH & Layer Lumping method for DED

$$Q_{flux} = \frac{A \cdot P}{V_{layer}} \cdot \frac{t_{layer}}{t_{heat}} l_f$$



(a) Time decomposition for a single layer (b) FH method schematic



Layer lumping method

Sim. parameters	Lumping configuration			
	No	2	4	8
Macro layers	100	50	20	10
Δz_t (mm)	0.45	0.9	1.8	3.6
Mesh elements	58970	37136	32203	28305

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Numerical model set-up

Multiphysics simulation COMSOL

Heat transfer in solids (ht)

- Laser heat input
- Heat losses (convective & radiative)

Solid mechanics (sm)

- Elasto-plastic model
- Non-linear material hardening (Voce)

Events (ev)

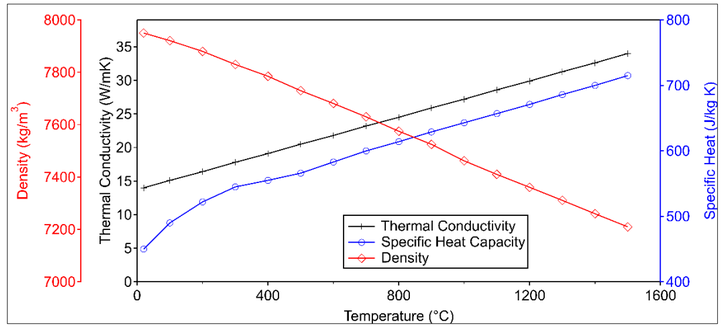
- Discrete states i.e., FH (1 or 0)
- Explicit Events (t_{heat} & t_{cool})

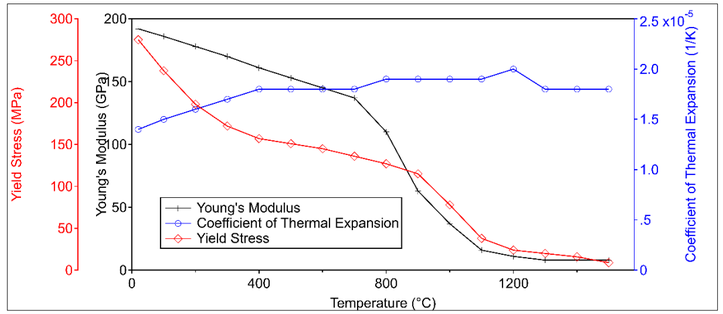
Multi-physics

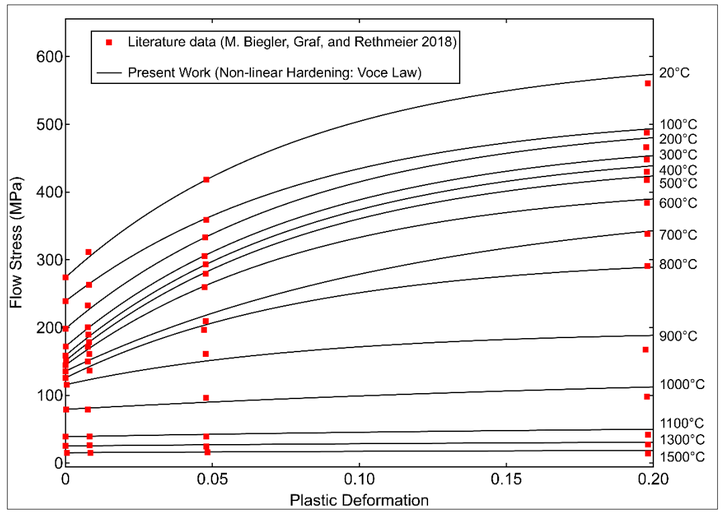
- Thermal expansion (te)
- Coupling link between ht & sm

Material

- Material activation: Quiet element (sm)
- Material properties f(T)







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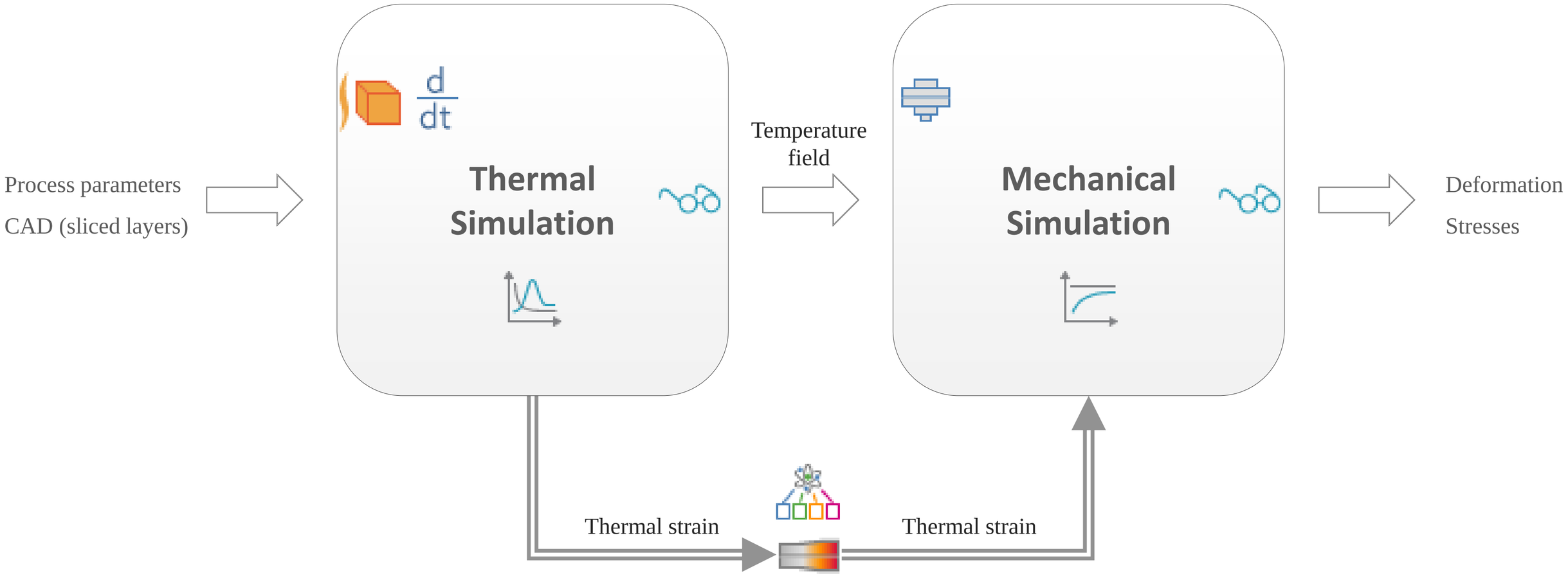
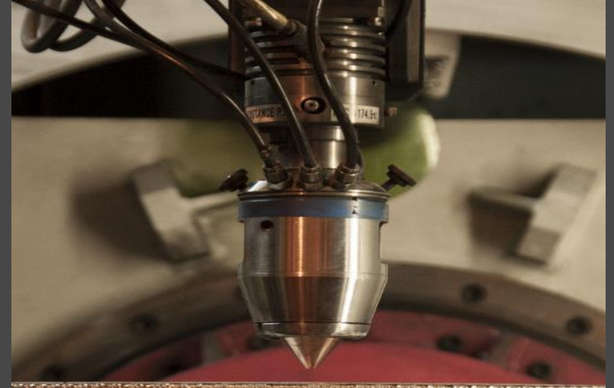
Numerical analyses

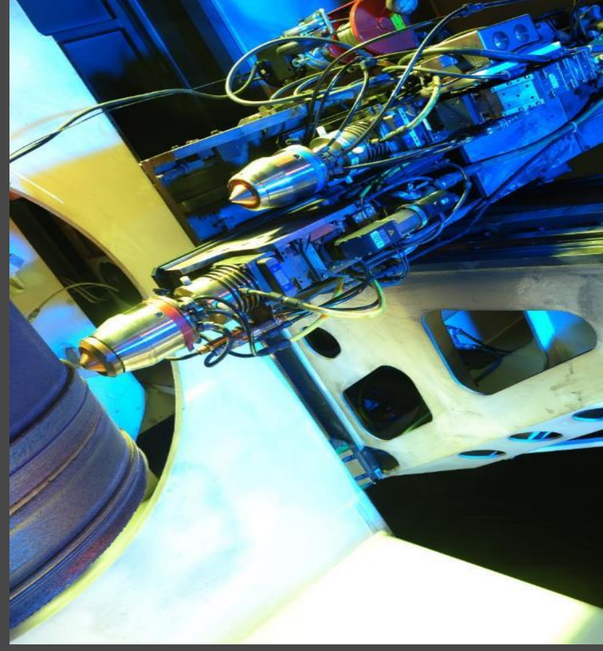
Sequential coupling



EXP v/s SIM

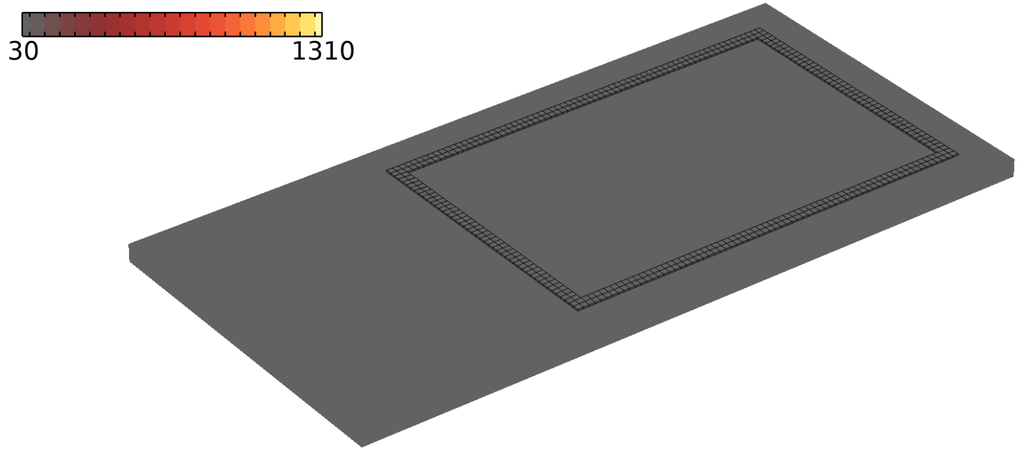
- Simulation results

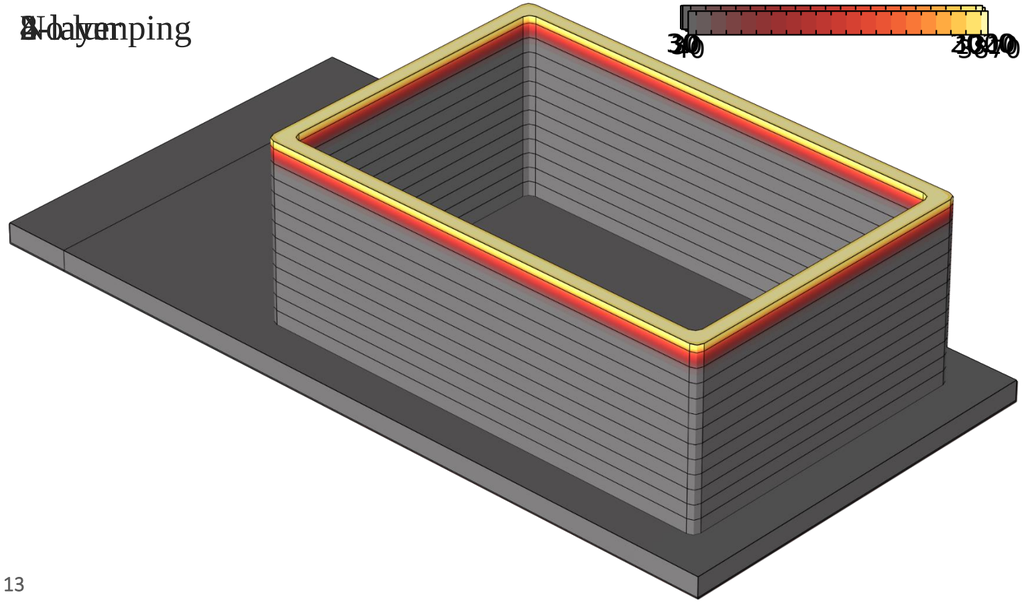


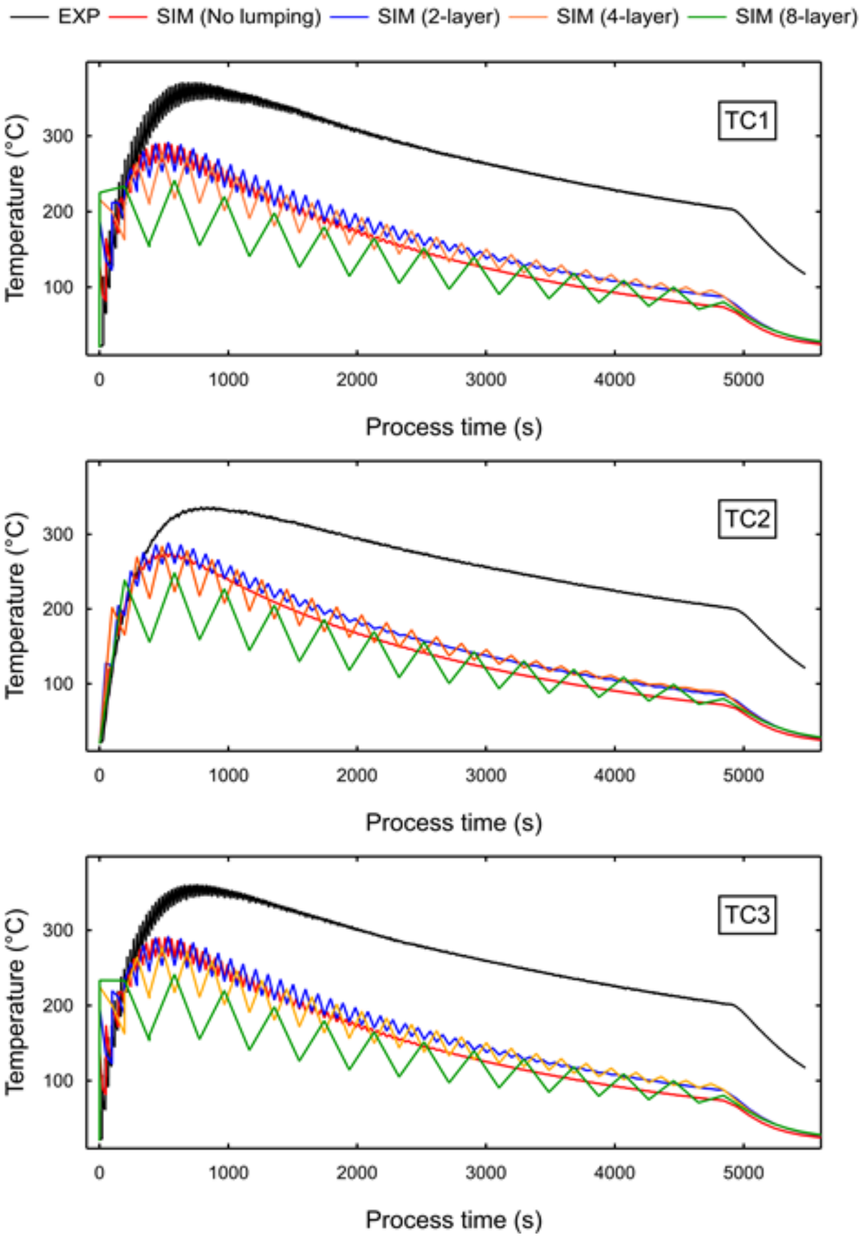


Simulation results

EXP v/s SIM (Thermal)







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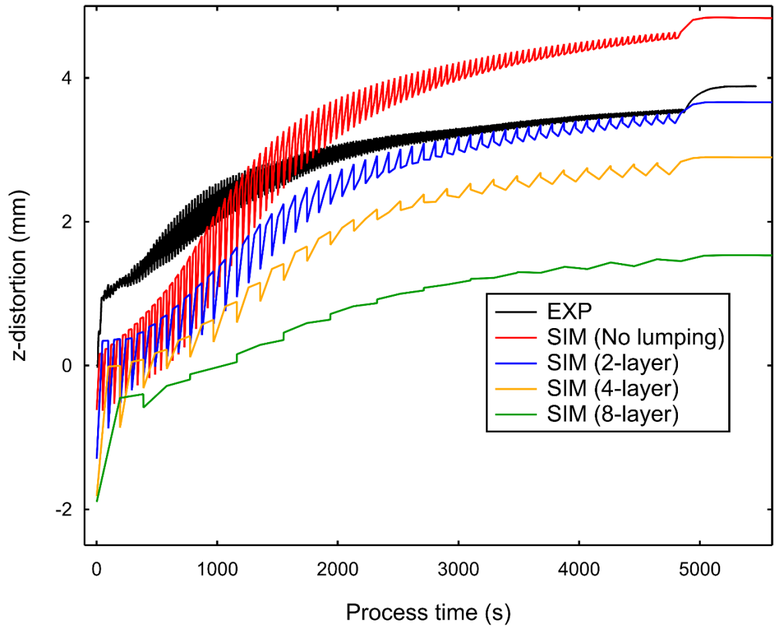
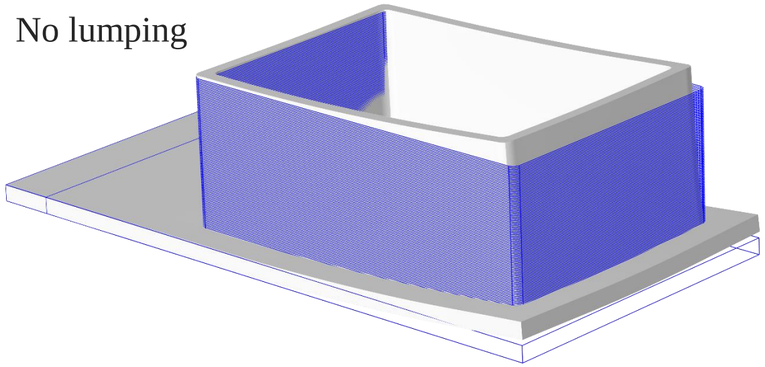
Simulation results

EXP v/s SIM (Mechanical)

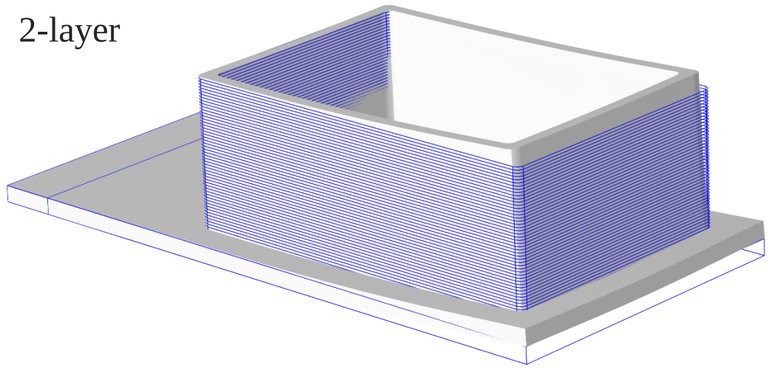
Final z-distortion (mm)	LDS location
Experimental	3.88
No-lumping simulation	4.83
2-layer lumping simulation	3.65
5-layer lumping simulation	2.89
10-layer lumping simulation	1.53



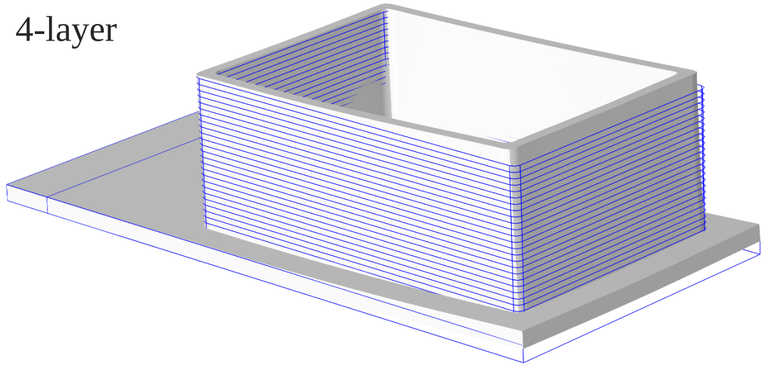
No lumping



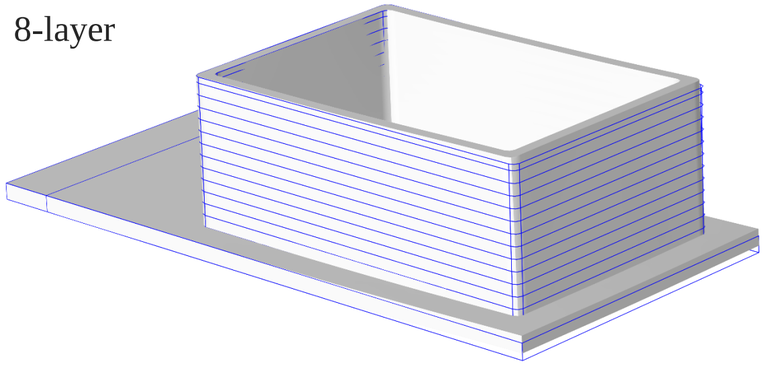
2-layer

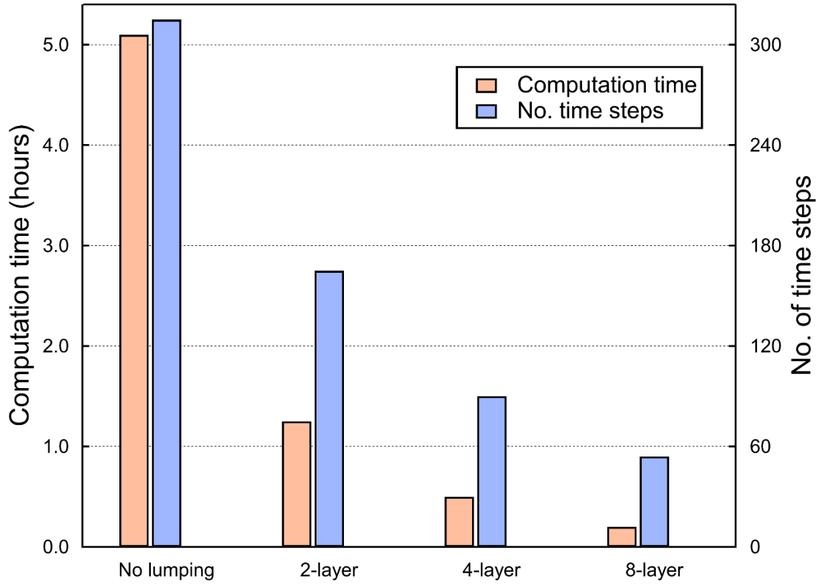


4-layer



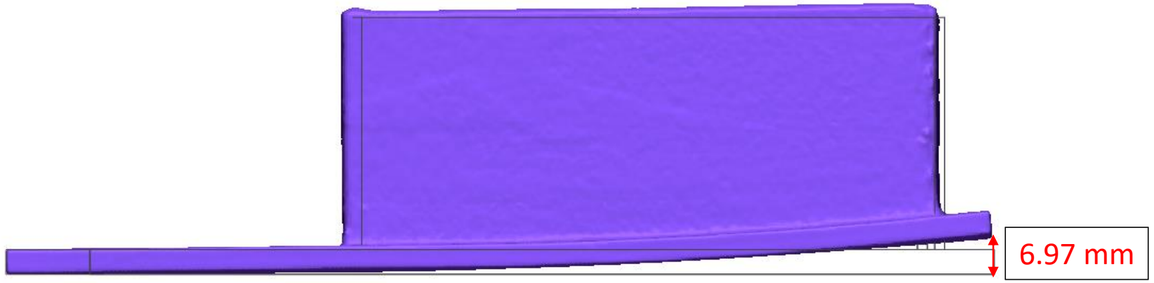
8-layer





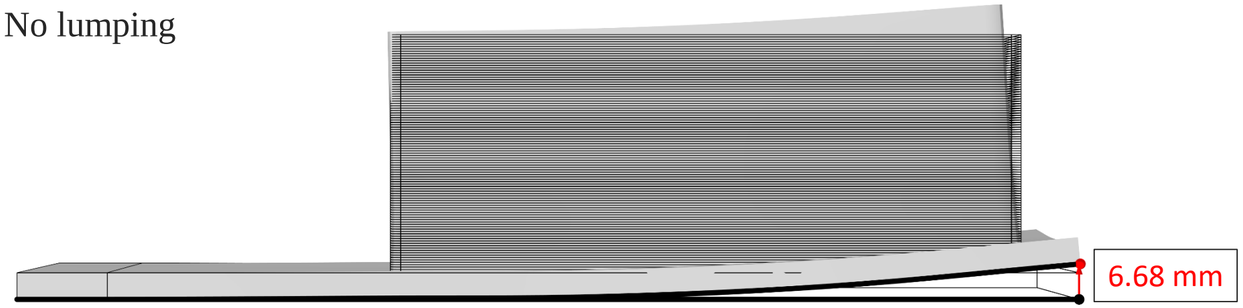
Simulation results

EXP v/s SIM (Mechanical)

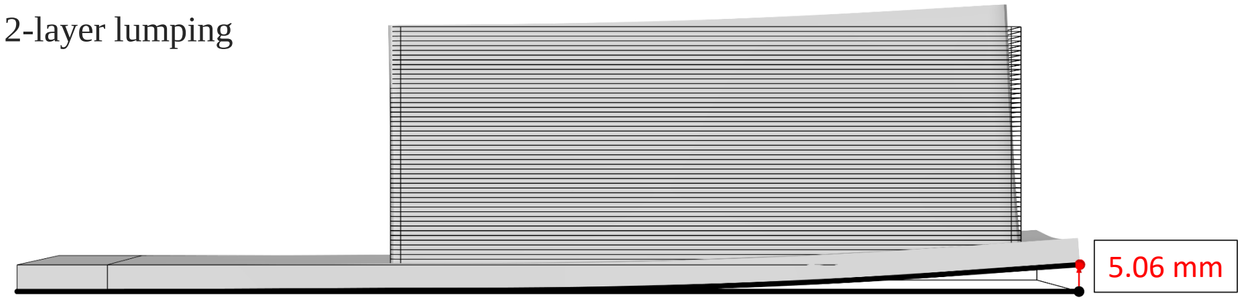


EXPERIMENT

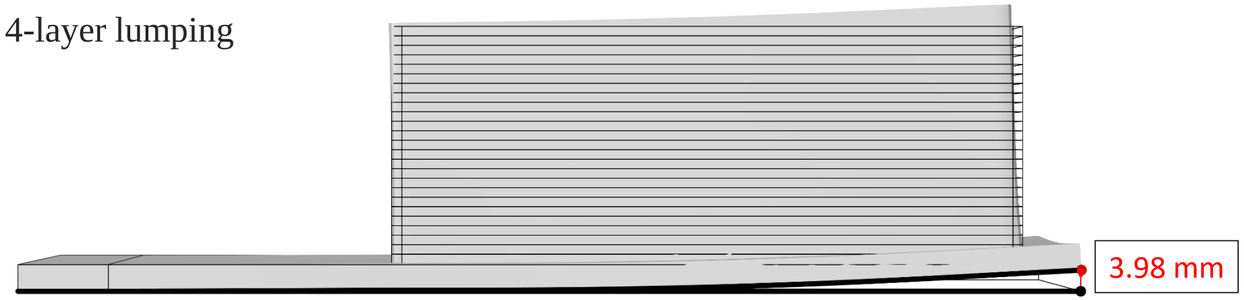
No lumping



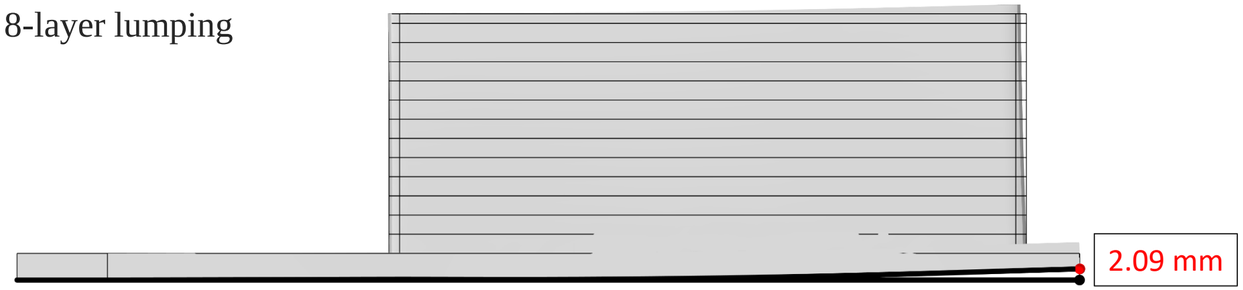
2-layer lumping



4-layer lumping



8-layer lumping



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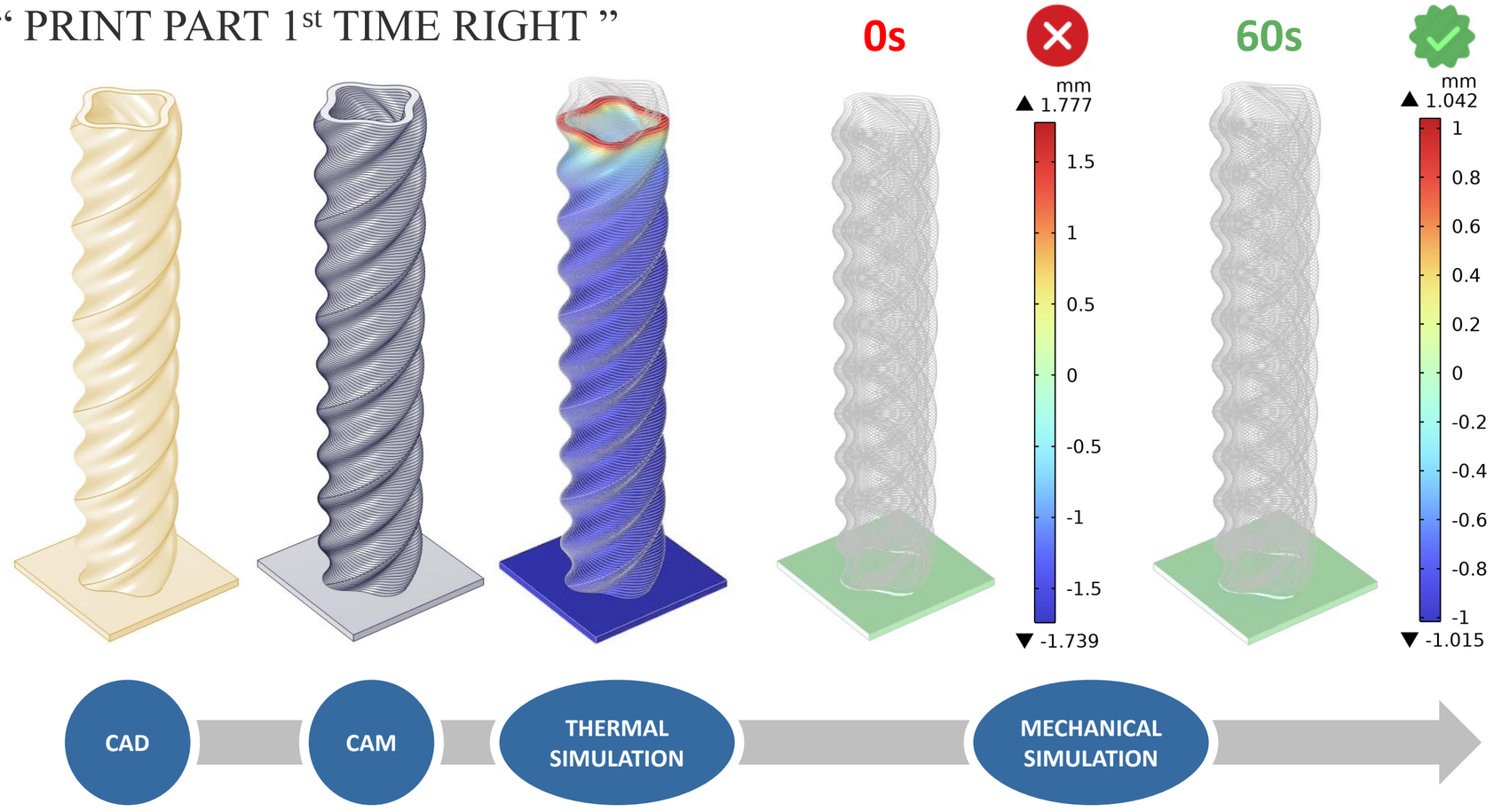
Project Impact!

- Industrial part simulation

Industrial part simulation

Computation time:
Thermal analysis: 65 min
Mechanical analysis: 32 min

“ PRINT PART 1st TIME RIGHT ”



CAD → CAM → THERMAL SIMULATION → MECHANICAL SIMULATION

AMFREE IREPA LASER INSTITUT CARNOT MICA PCM

Helical rotor of a Moineau™ cavity pump

Size *Ø128x660mm*

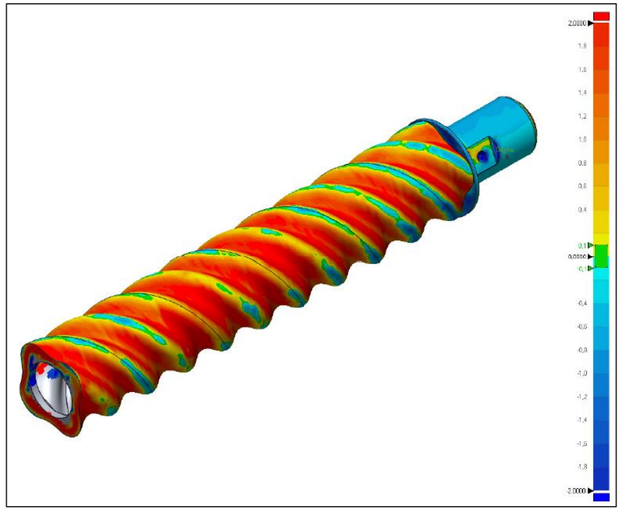
Influence of inter-layer dwell time (SIM)

With an addition of 60s in simulation (optimized value)

- Peak temperatures are controlled during fabrication.
- Deformation is reduced by 43%. Validated with EXP data.
- Complex part “ PRINTED 1st TIME RIGHT “.

Size 128 x 660 mm

Fabricated part with *60s* cooling



EXP: DEFORMATION

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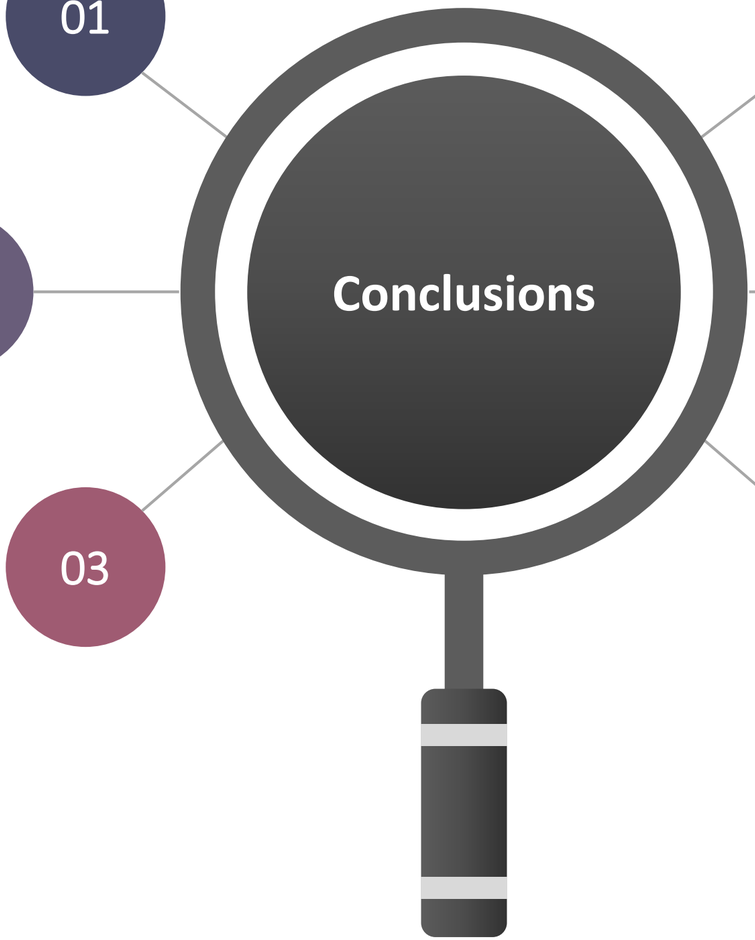
Conclusions



01 FH method with energy conservation rule is accurate

02 Layer lumping drastically reduces the computation time

03 Layer lumping negatively affects computation accuracy

04 Layer lumping size needs to be calibrated

05 Suitable for large-part simulation

06 Further validation on industrial part is required

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Contact-us !

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