Addition of a finite element activation method in an existing thermomechanical finite element code to model AM

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LTAS-MN²L

Layout

1. Context
2. Method description
3. Thermal simulations and verification
4. Extension to thermomechanical
5. Conclusion

Our lab within the university

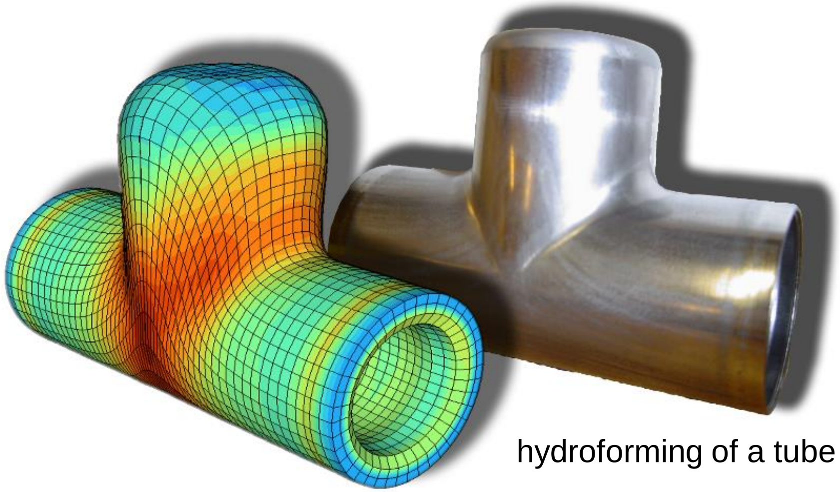
LIÈGE université

LIÈGE université Sciences Appliquées

(Faculty of Applied Sciences)

LTAS

Dept of Aerospace and
Mechanical Engineering



hydroforming of a tube

Lab Software: Metafor – nonlinear Finite Element software – LTAS-MN²L

Computational Mechanics

Keywords

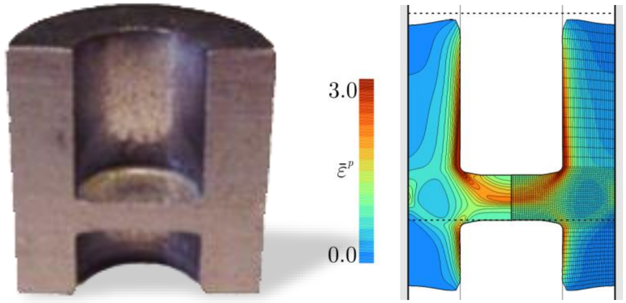
- Numerical simulation
- Solid mechanics
- Finite element method
- Software development

J.-P. Ponthot

Our main simulation code: Metafor

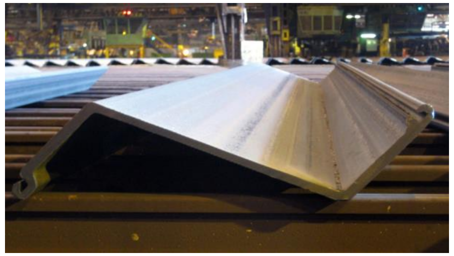
Implicit Finite-Element solver
for the numerical simulation of large deformations of solids

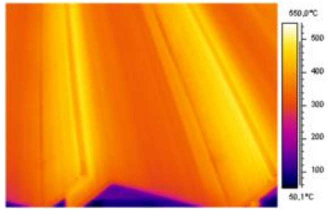
Metal Forming applications



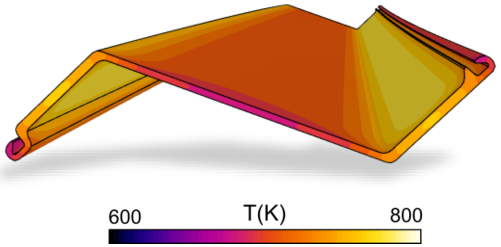
- ALE Formalism, remeshing.
- **Thermomechanical** time-integration schemes.

Thermomechanical

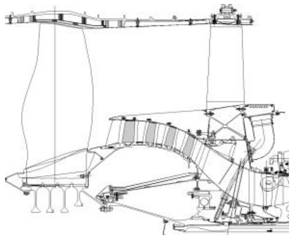


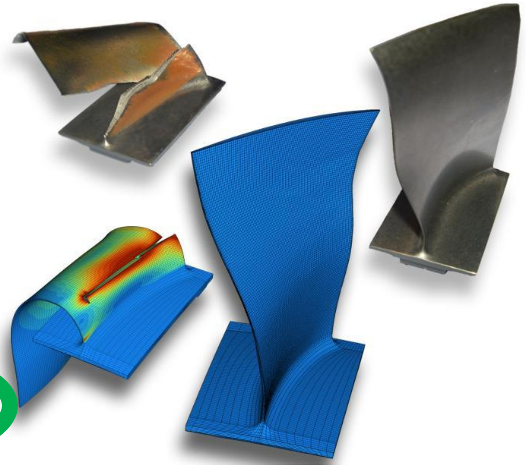


ArcelorMittal



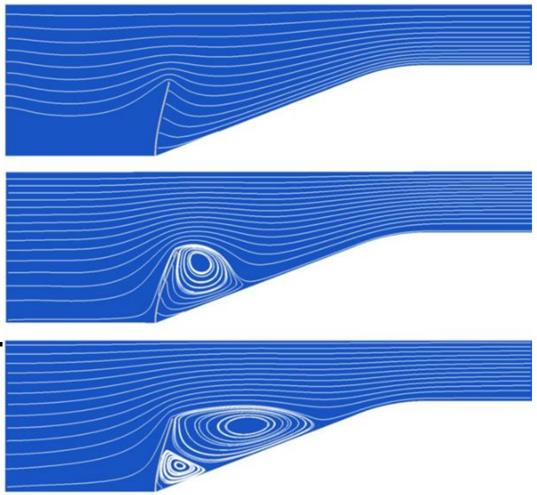
Crash / Impact





- Modelling of **cracks**, fracture.
- Contact algorithms.

Fluid/structure interaction



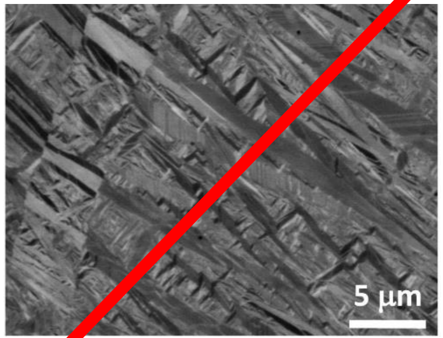
- Fluid finite elements.
- Monolithic schemes.
- Coupling with extenal solvers.

My thesis

Thesis:
Prediction of the residual stresses in macro-scale parts created by AM processes using the in-house FEM software Metafor.

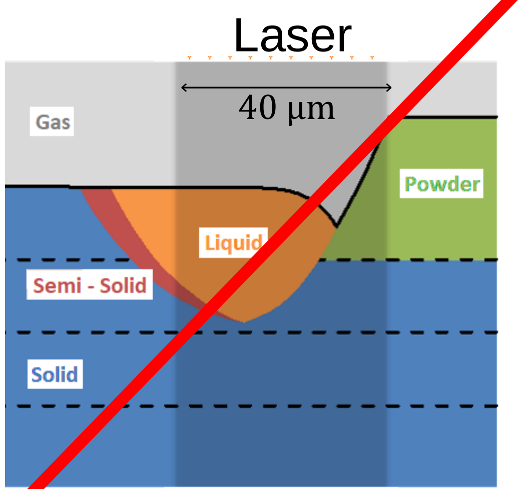
Focus?
- **Numerical method,**
- **Mesh Management,**
- **Accurate macro-scale.**

Micro scale



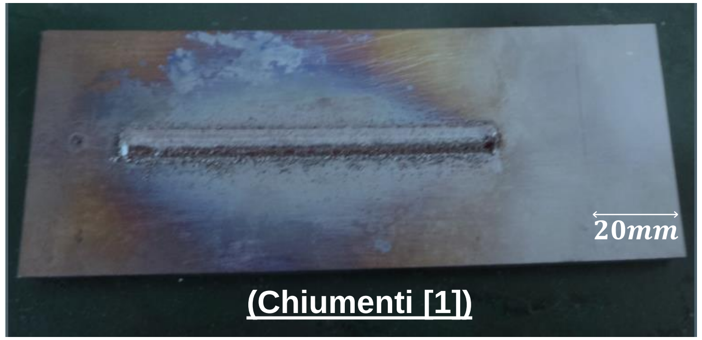
Source: W. Xu et al., Additive manufacturing of strong and ductile Ti–6Al–4V by selective laser melting via in situ martensite decomposition, Acta Materialia, 2015

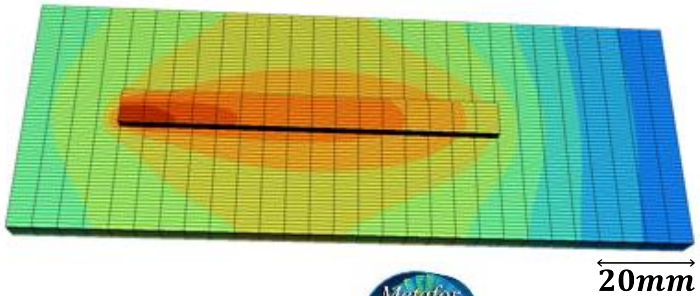
Meso scale



Adapted from: Qiang Chen et al., Numerical modelling of the impact of energy distribution and Marangoni surface tension on track shape in selective laser melting of ceramic material, Additive Manufacturing, March 2018

Macro scale / part scale



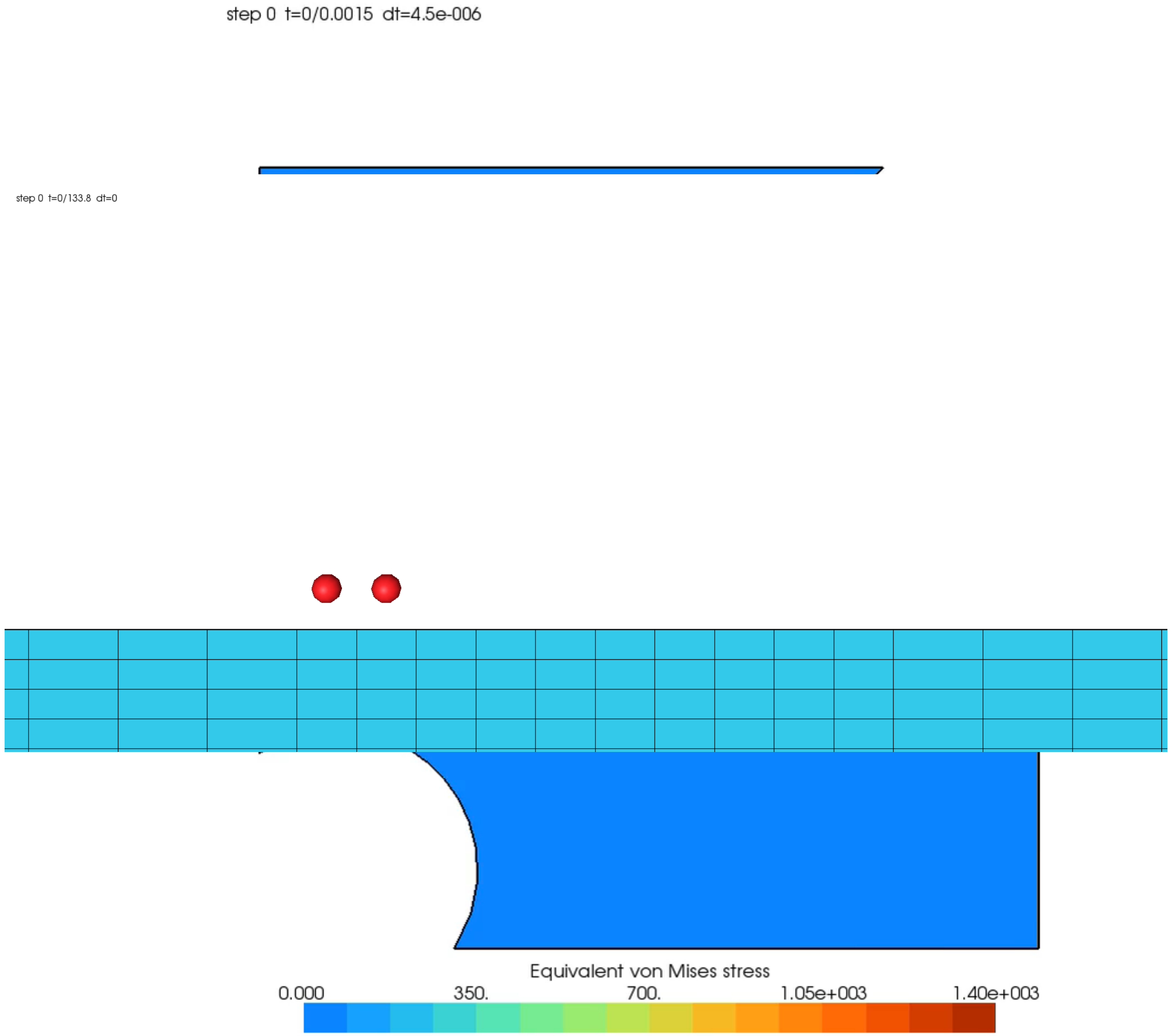


Activation Method

Idea to model AM
→ Similar approach as crack propagation simulations.

In crack propagation
→ A criteria is computed at each element.
→ If it fails, the element is automatically deactivated

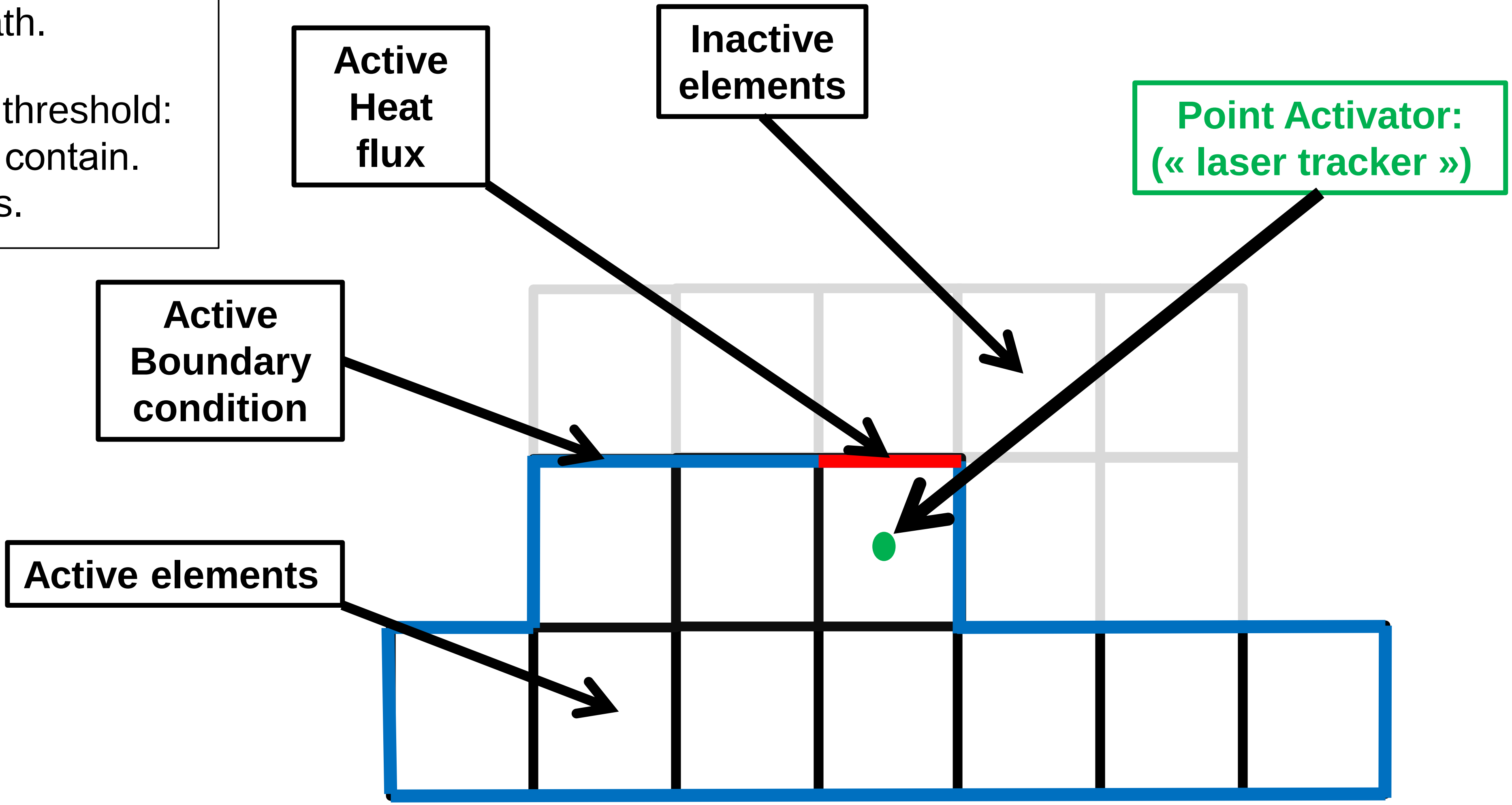
Application to AM
→ Define an **activation criteria** that is checked at each element.
→ **Automatic activation** when criteria is met.



Choice of activation criteria?

Criteria?
Element contains a **laser tracker point**, with a predefined path.

→ Very simple criteria and threshold:
Criteria=0 element doesn’t contain.
Criteria=1 element contains.



Activation algorithm

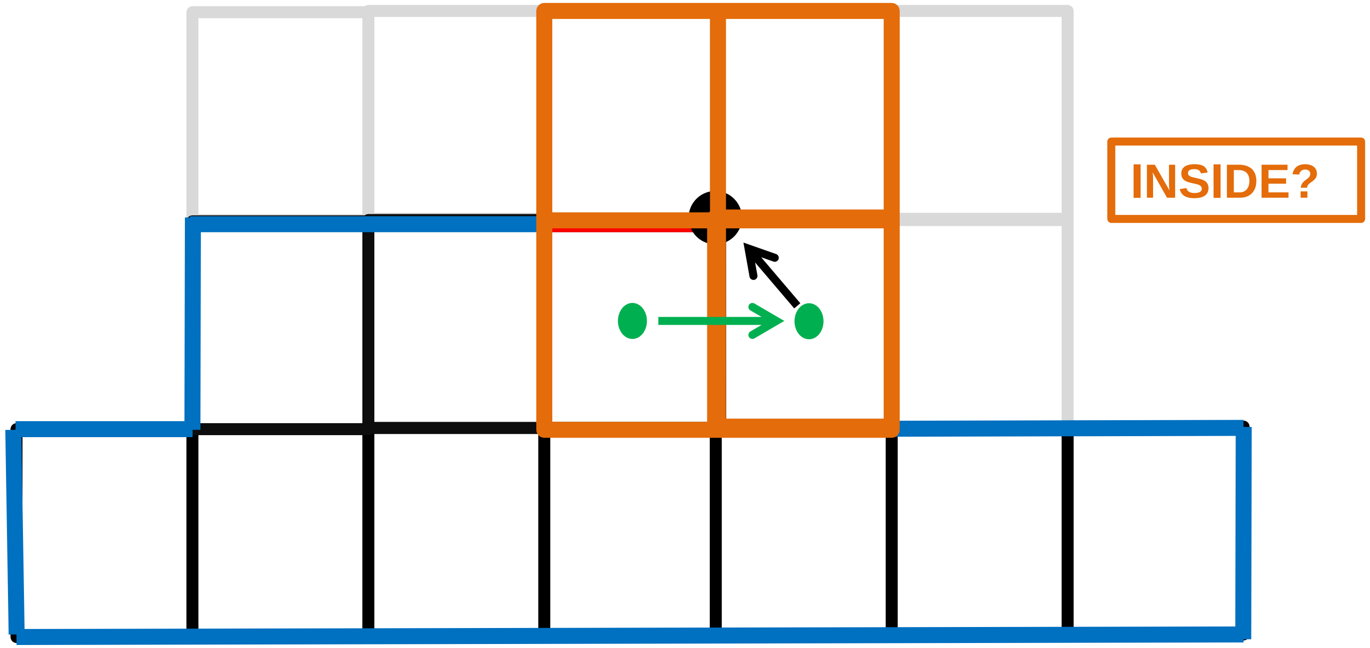
Update criteria

1) Find the elements in the neighbourhood

2) Check if one contains the laser tracker

3) Set Criteria=1
→ To be activated

New Time Step



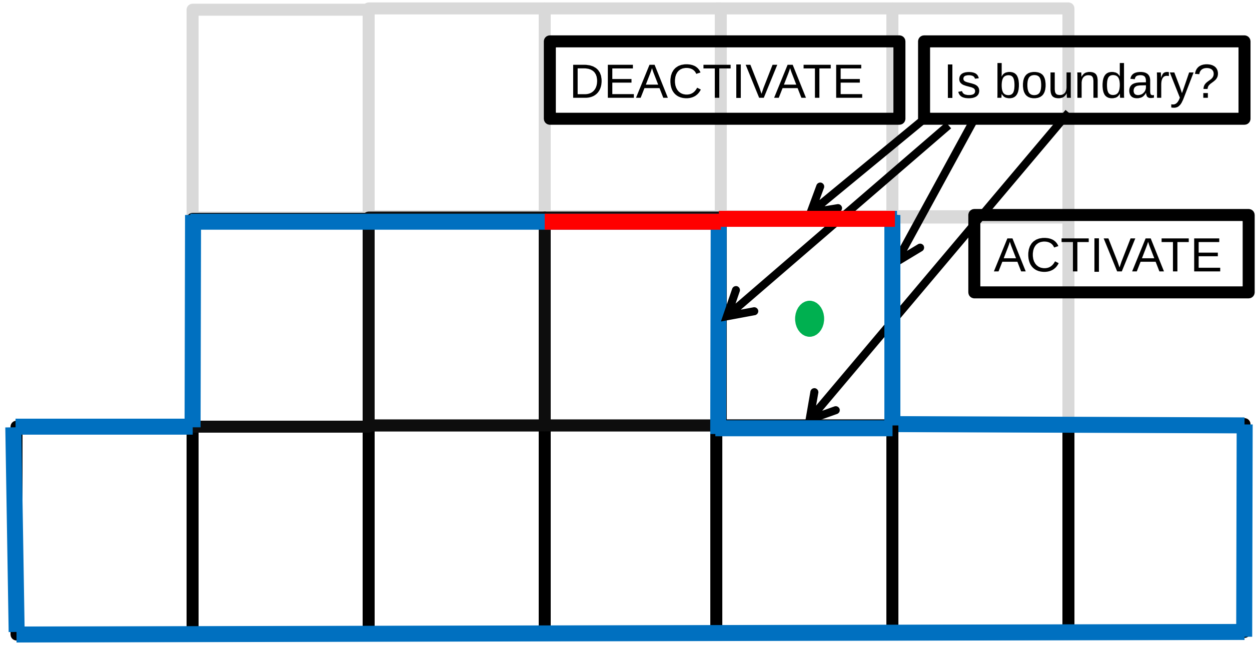
Activation algorithm

Automatic Activation

1) Deactivate all heat flux
2) Activate elements
3) Is Boundary?
4) If yes: Activate
5) If No: Deactivate
6) Activate heat flux where needed

Update criteria

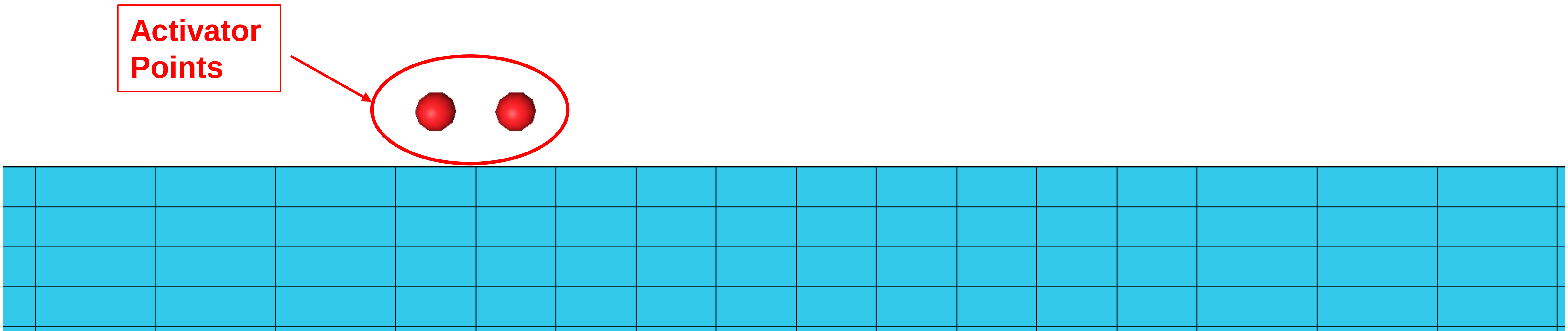
1) Find the elements in the neighbourhood
2) Check if one contains the laser tracker
3) Set Criteria=1 → To be activated



2D example

Example of activation with a Point Activator

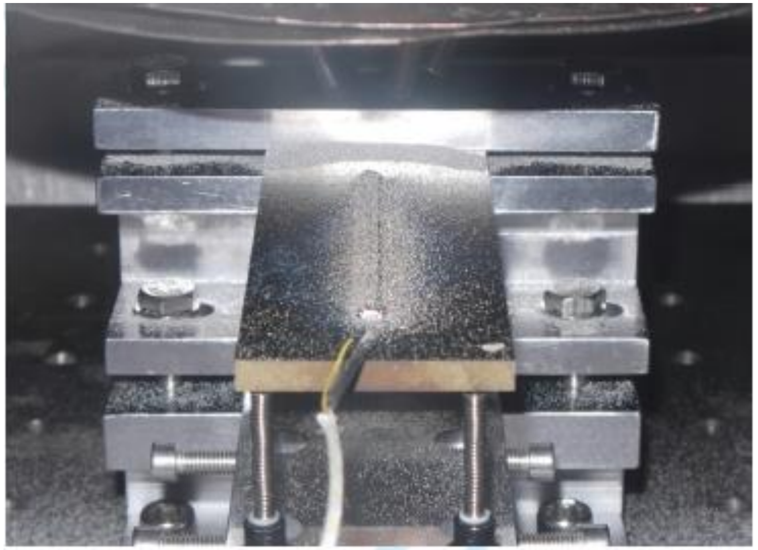
step 0 t=0/133.8 dt=0



Verification: test Chiumenti et al.[1]

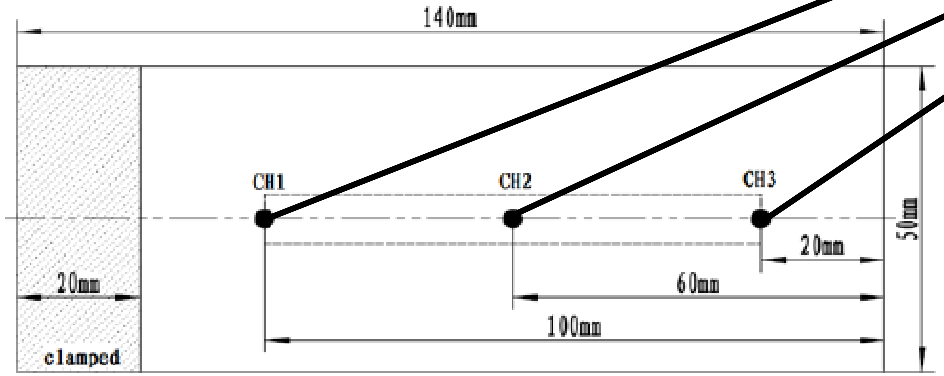
Process parameters:

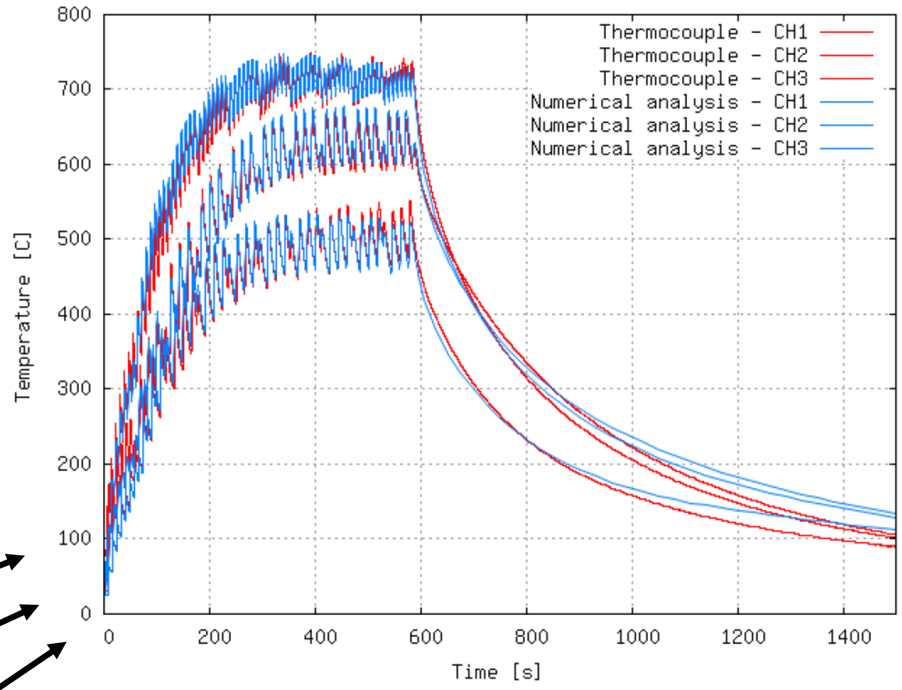
- Laser Metal Deposition
- Blown-Powder
- Material: Ti6Al4V
- Laser Power: [2kW]
- Deposit Speed: 10[m/s]
- Deposit size: 80x7x2,8[mm]
- Nb. Of Layers: 10

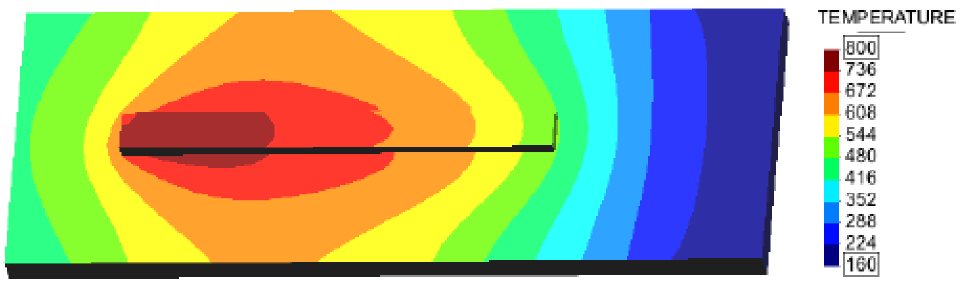


Simulation parameters

- Pure thermal
- 10050 elements
- Heat source:
  - Volumic
  - Constant per element







[1] M. Chiumenti et Al., "Numerical simulation and experimental calibration of Additive Manufacturing by blown powder technology. Part I: thermal analysis", Rapid Prototyping Journal 23 (2) (2017) 448–463.

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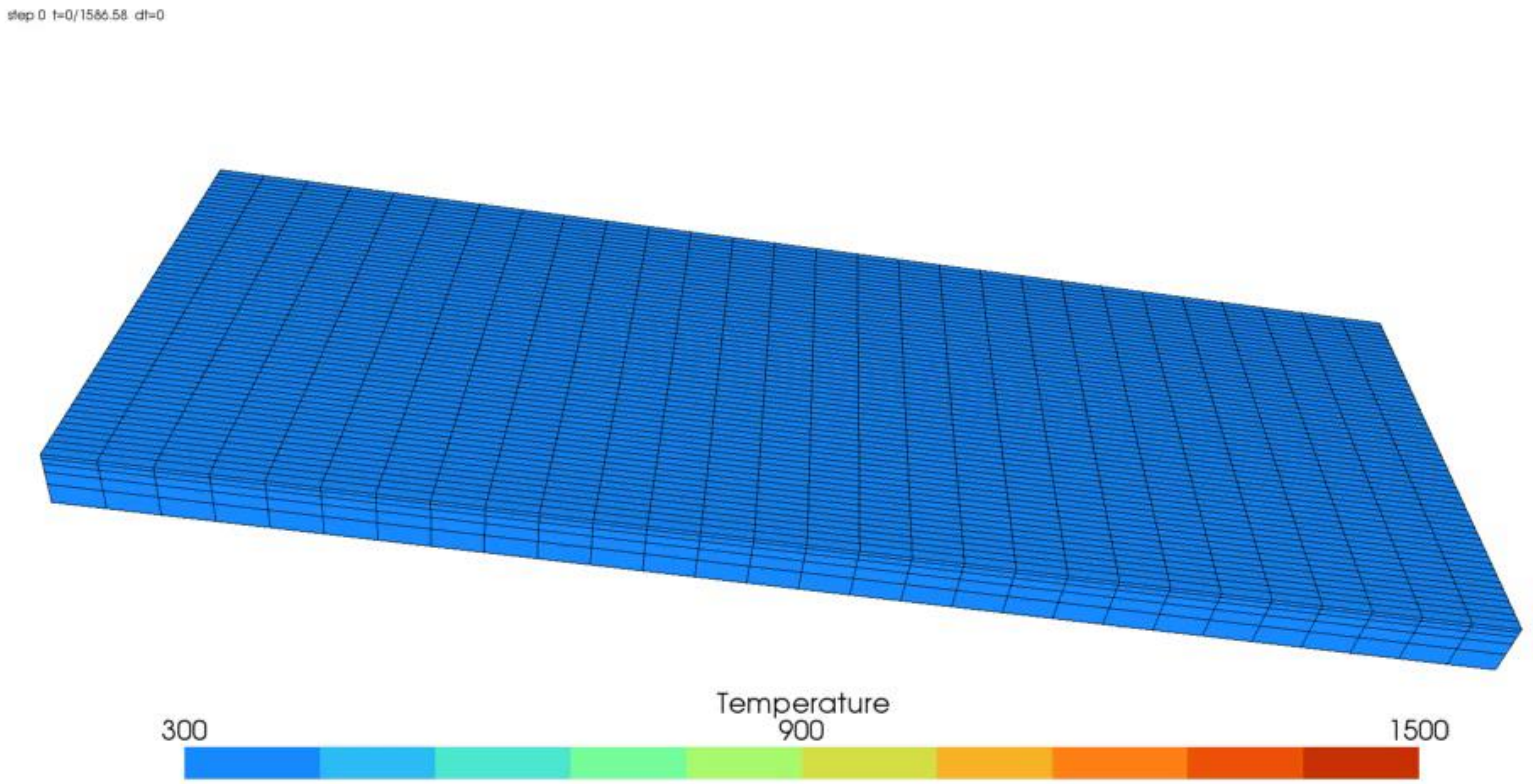
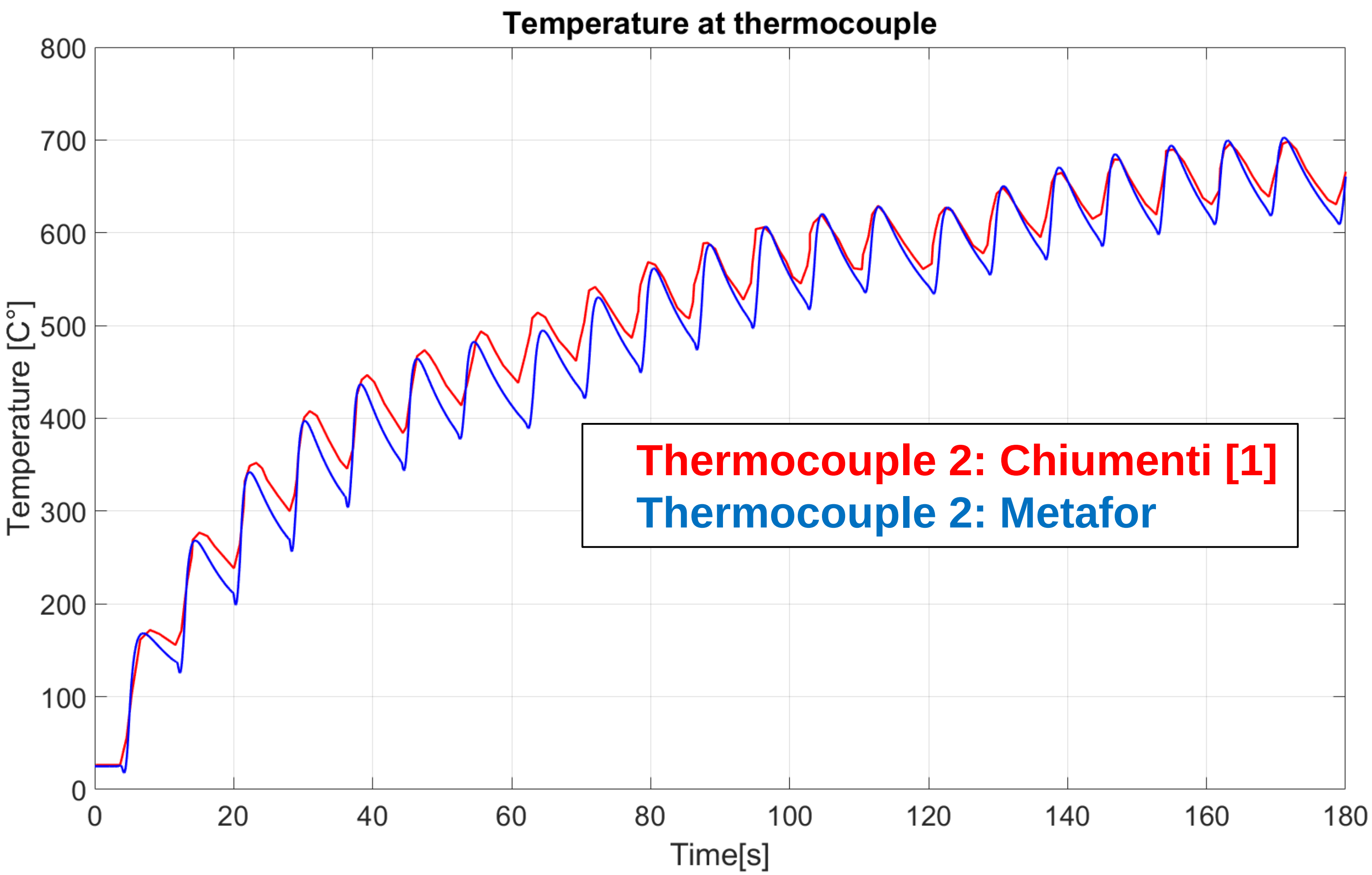
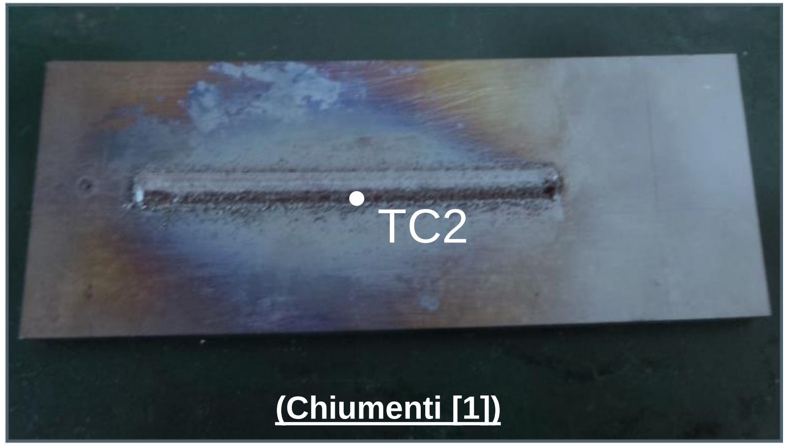


Verification: test Chiumenti et al.[1]

Reproduction of a simulation from Chiumenti et al.[1]:
→ Good agreement of the results.
→ **Investigation of differences ?**





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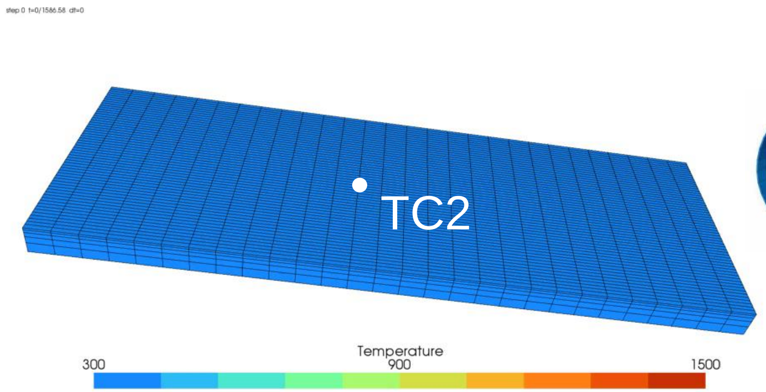
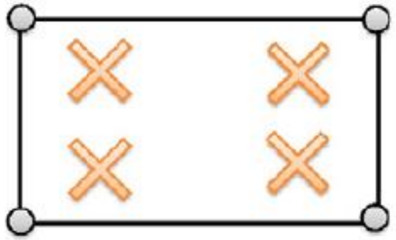


Lobatto Integration?

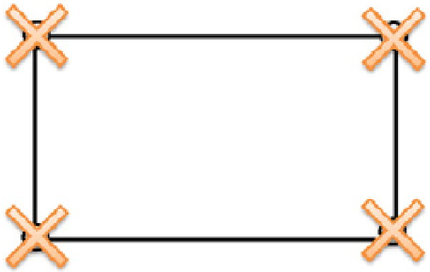
In the Metafor simulation:
- Gauss integration was used

In the simulation from the article:
- Lobatto integration was used

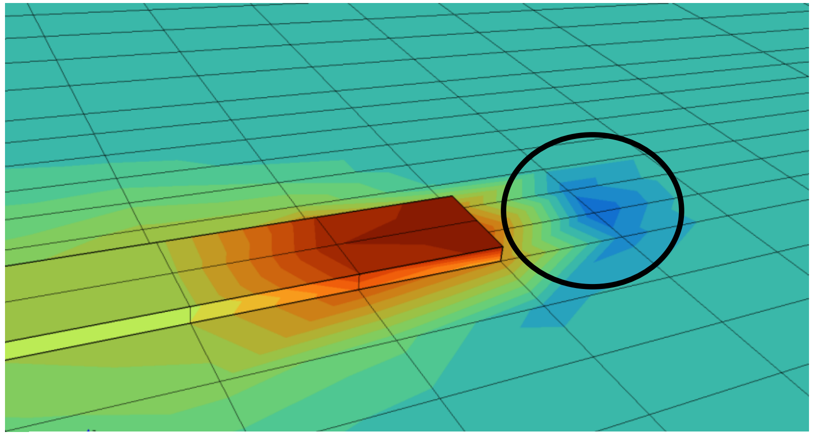
Why Lobatto integration?
Lobatto integration reduces over/undershoots of T° due to the very high temperature gradients.



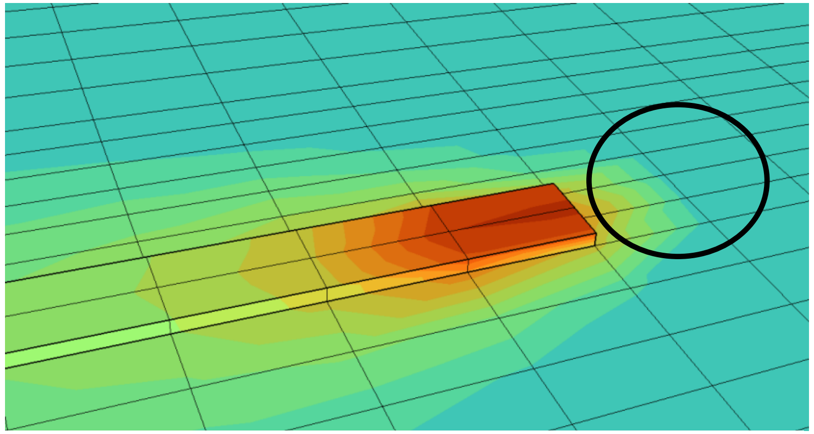
Gauss vs Lobatto integration:
-Non-physical undershoot of the temperature can be seen

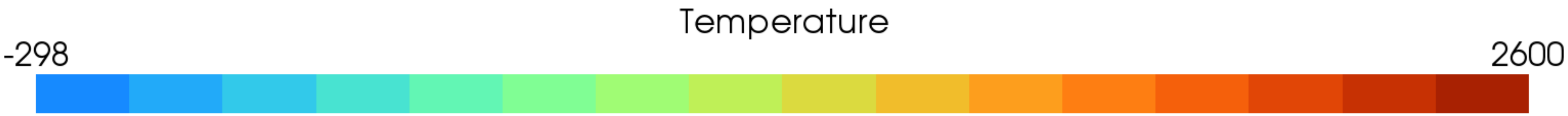


GAUSS

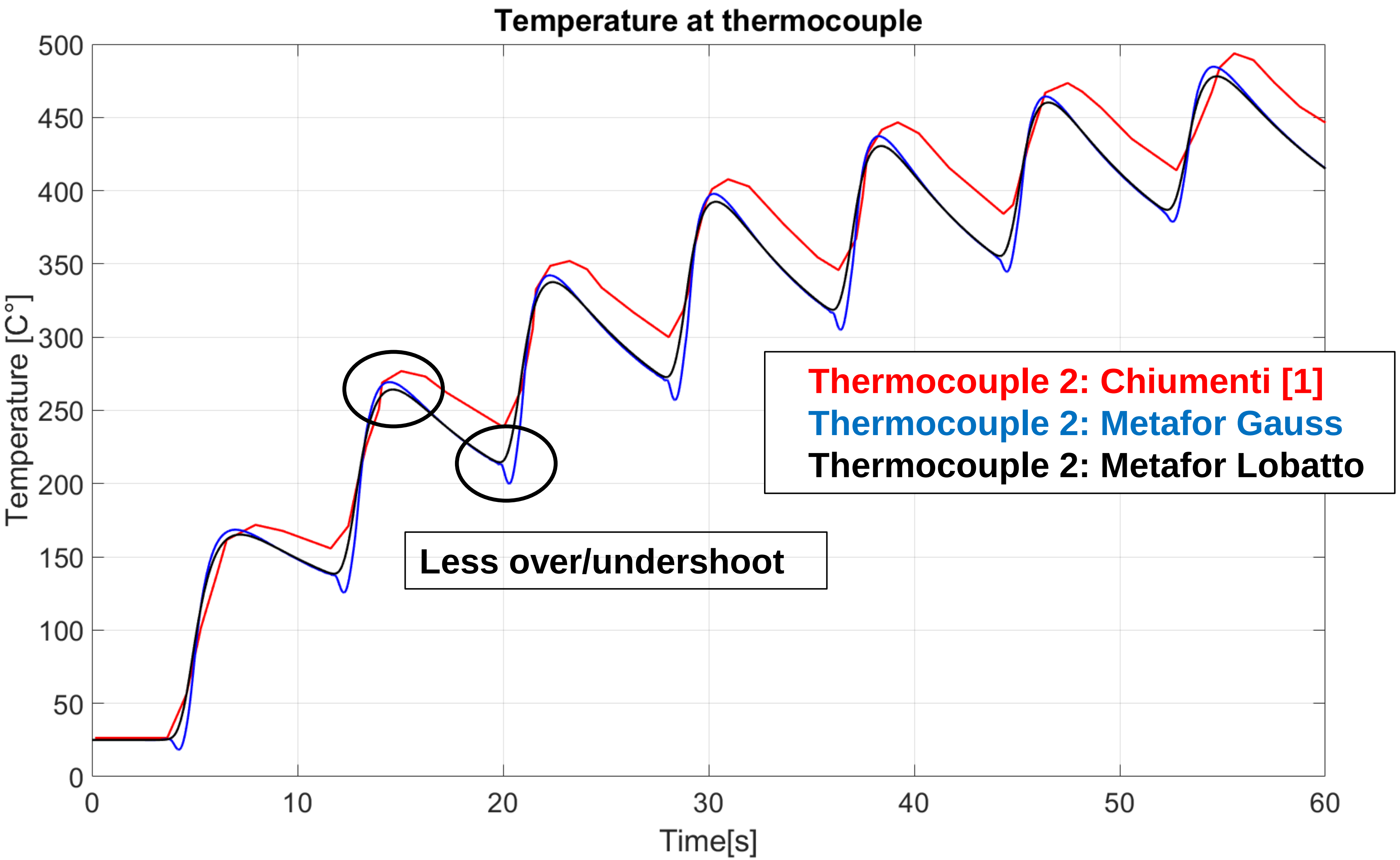


LOBATTO





Lobatto Integration?

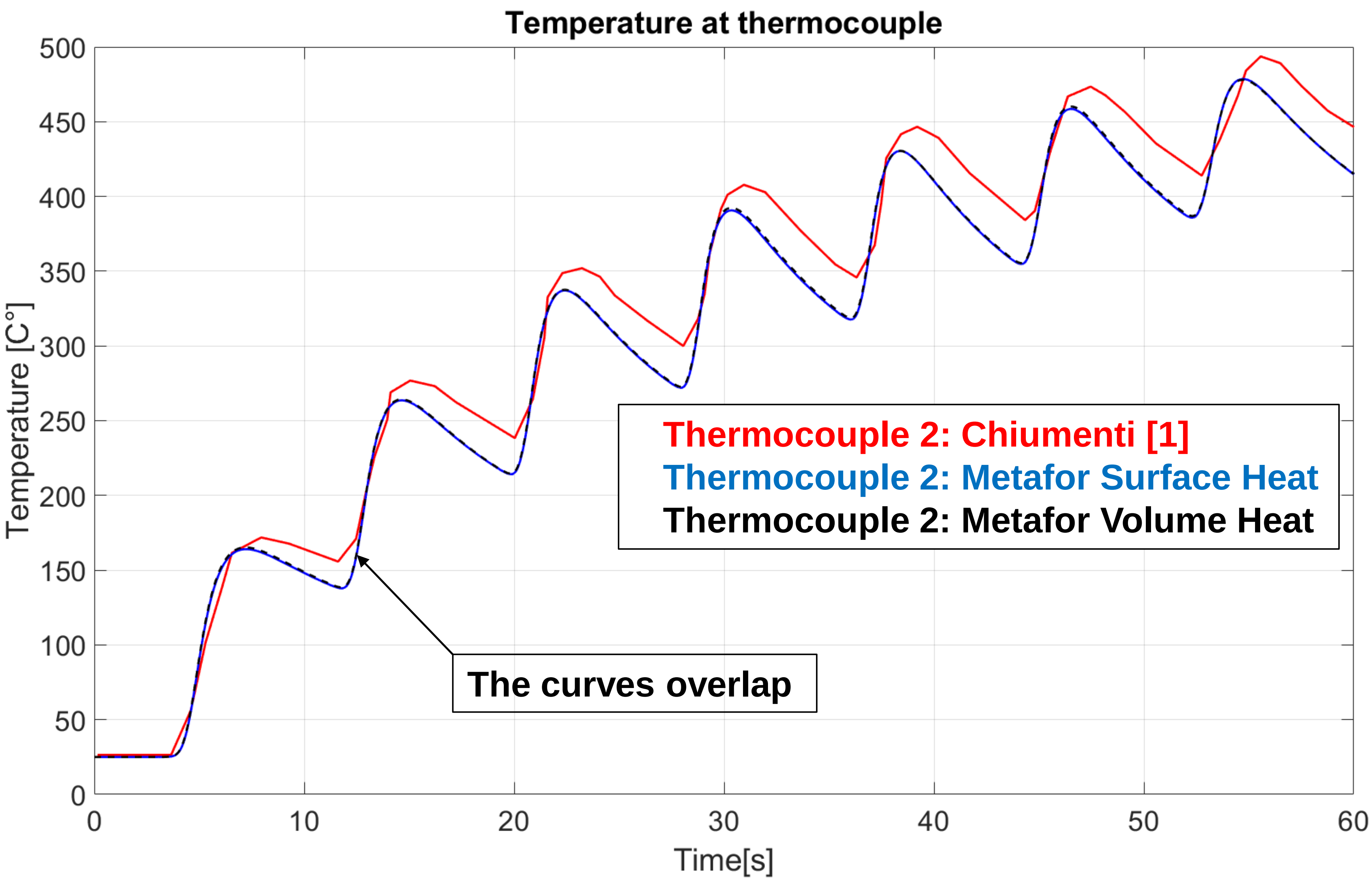


Volumic Heat Flux?

Metafor simulation:
→ Surfacic heat flux to model the laser flux

Chiumenti [1]:
→ Volumic heat input on the currently activating layer

Implementation of volumic heat input in Metafor:
→Negligeable effect
→Thermocouple is far enough from the source



Conclusion on thermal simulations

Conclusion on thermal simulations:

- The code can reproduce results from the literature with a reasonable accuracy.
- The remaining differences are probably code specific errors.

Possible improvements:

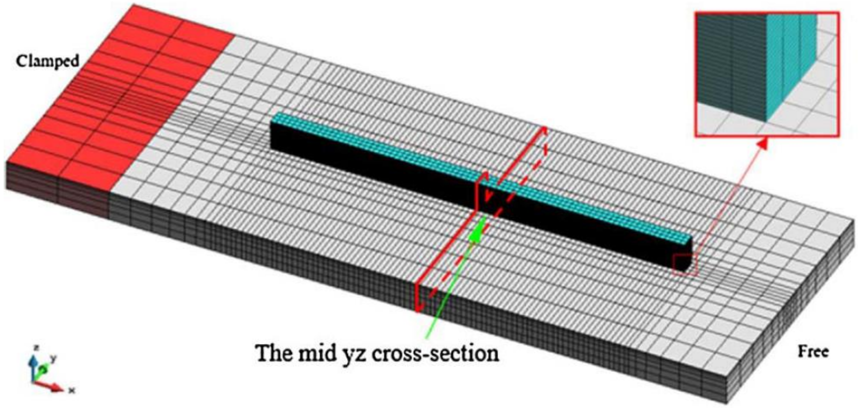
- **Extend to thermomechanical (Ongoing):**
  - Handle the mesh distorsion.
  - Handle the temperature dependant mechanical properties.
  - Implement a stress relaxation temperature.

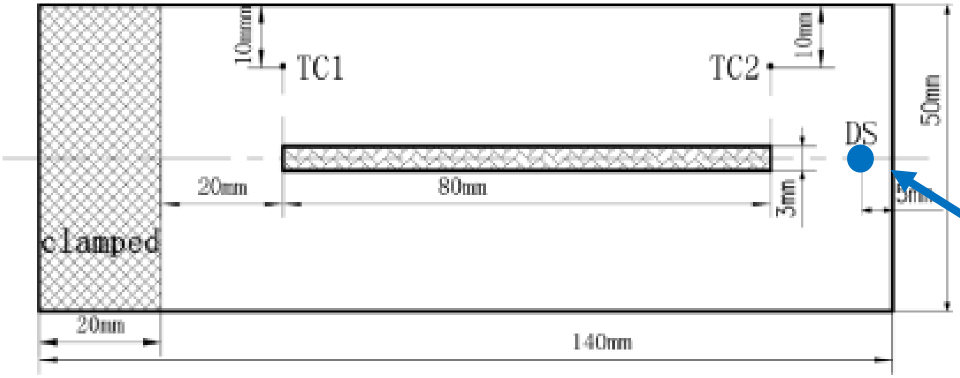
Thermomechanical test: Lu et al.[2]

Thermomechanical test:
Lu et al.[2]:

- Laser Metal Deposition
- Blown-Powder
- Material: Ti6Al4V
- Laser Power: 2[kW]
- Deposit Speed: 10.0[m/s]
- Deposit size: 80x3x6[mm]
- Nb of layers: 40

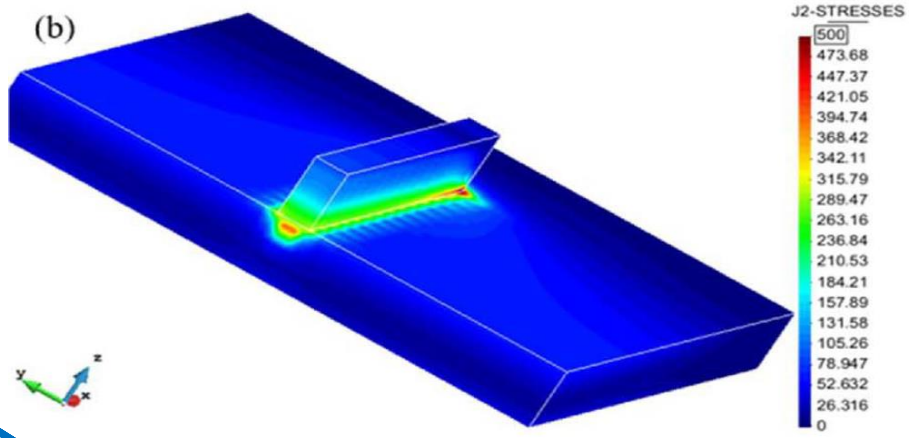
- 19,614 elements
- Material model:
  - Thermo-elasto-plastic perfectly plastic.





[2] X. Lu et al., *Finite element analysis and experimental validation of the thermomechanical behavior in laser solid forming of Ti-6Al-4V*, 2017

J2-Stresses

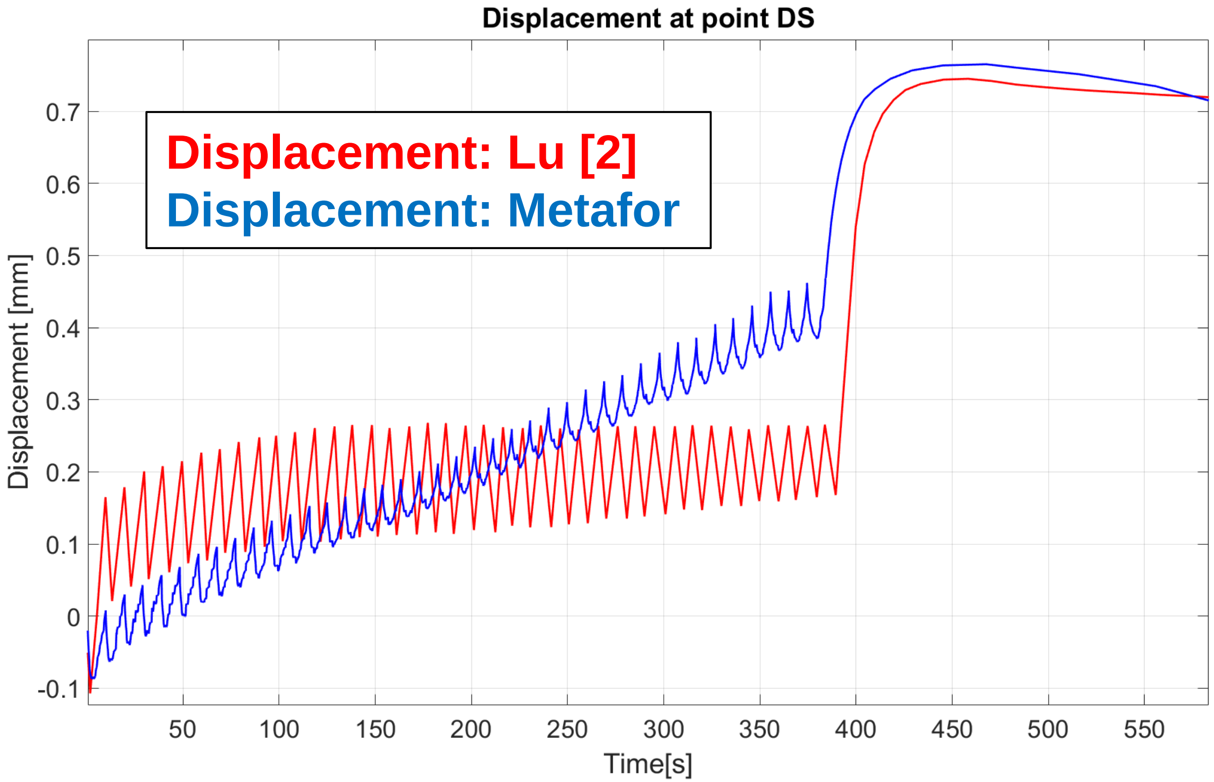


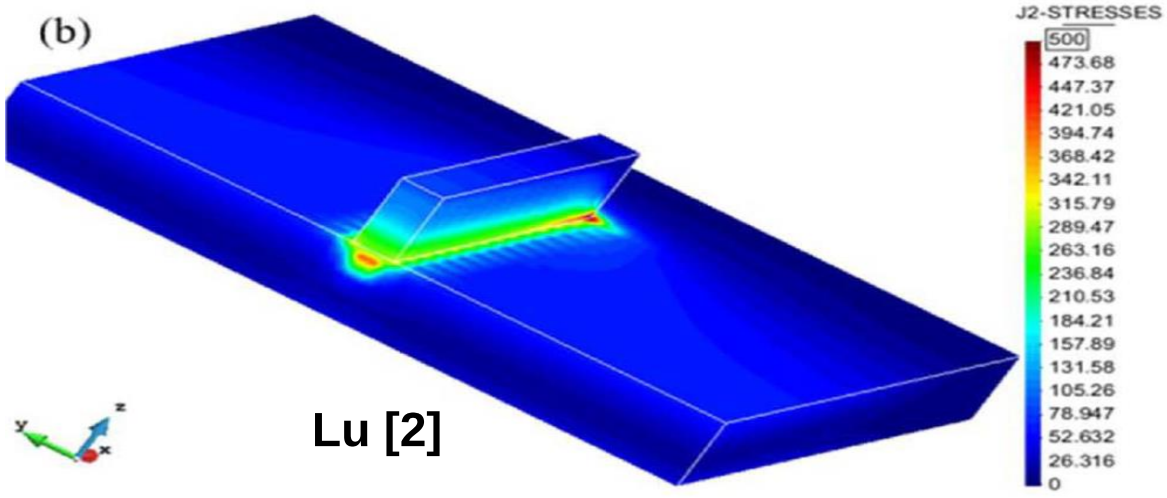
Displacement sensor

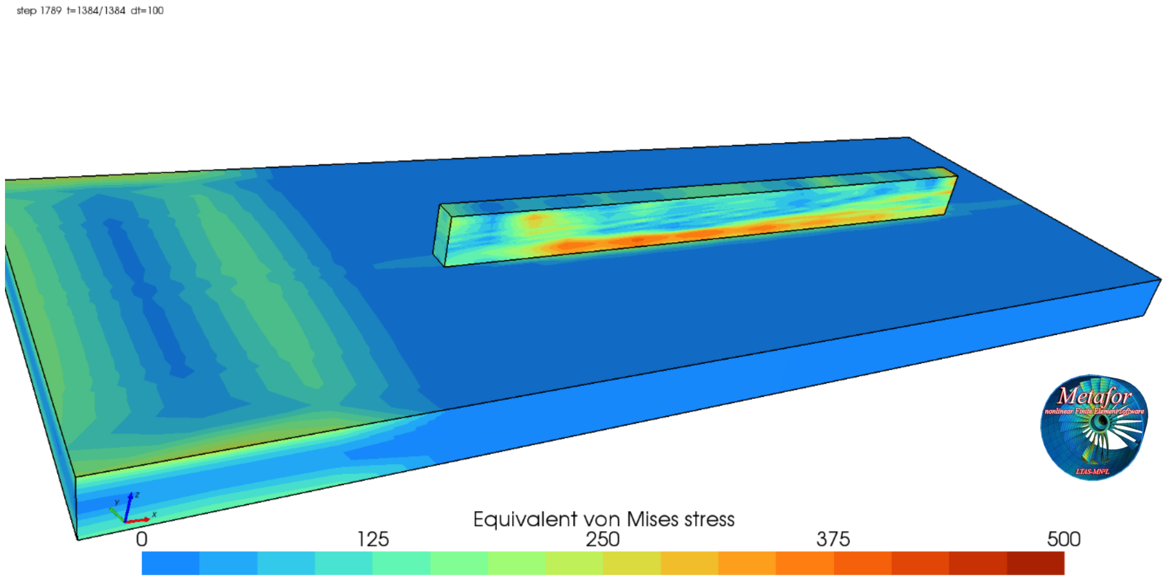
Thermomechanical test: Lu et al.[2]

1st thermomechanical results:
Different from the literature

Main cause:
Lack of "stress relaxation temperature" implementation in Metafor .







Conclusion

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- The code can reproduce results from the literature with a reasonable accuracy.
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Possible improvements:

- **Extend to thermomechanical (Ongoing):**
  - Handle the mesh distorsion.
  - Handle the temperature dependant mechanical properties.
  - Implement a stress relaxation temperature.
- **Implement a more complex heat input and activation volume (Future Work).**
- **Implement better mesh management techniques (Future work):**
  - Example: dynamic remeshing methods with non-conformal elements.