Finite Element activation strategy in the numerical simulation of Additive Manufacturing Processes

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Context and challenges

- This work consists in building a first **3D thermal Finite Element Analysis** of an **additive manufacturing process** in the fully **implicit** in-house Finite Element code "**Metafor**" [1].

- The **challenges** of such a simulation come from multiple sources:
  - The nature of the process requires a **large deformation thermo-mechanical simulation**.
  - The modeling of the material law is complex.
  - The geometry of the process imposes a **very fine discretization** for accurate results.
  - The process requires **altering the mesh geometry of the model during the simulation** to model the addition of matter.

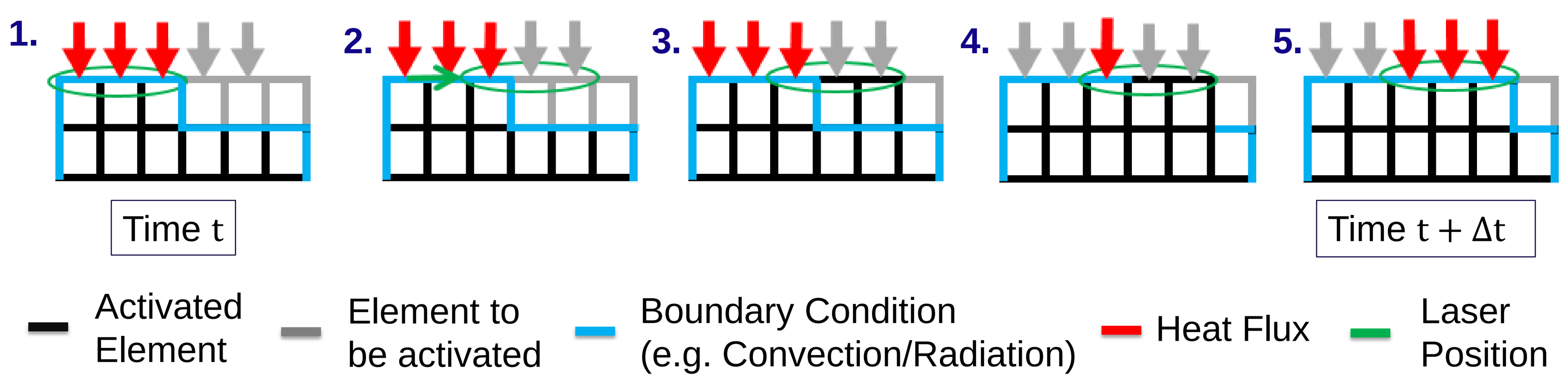
- **This work is a preliminary work to asses the current possibilities of additive manufacturing modelling of Metafor. It focuses on mesh and geometry management.**

Mesh management technique

Principle

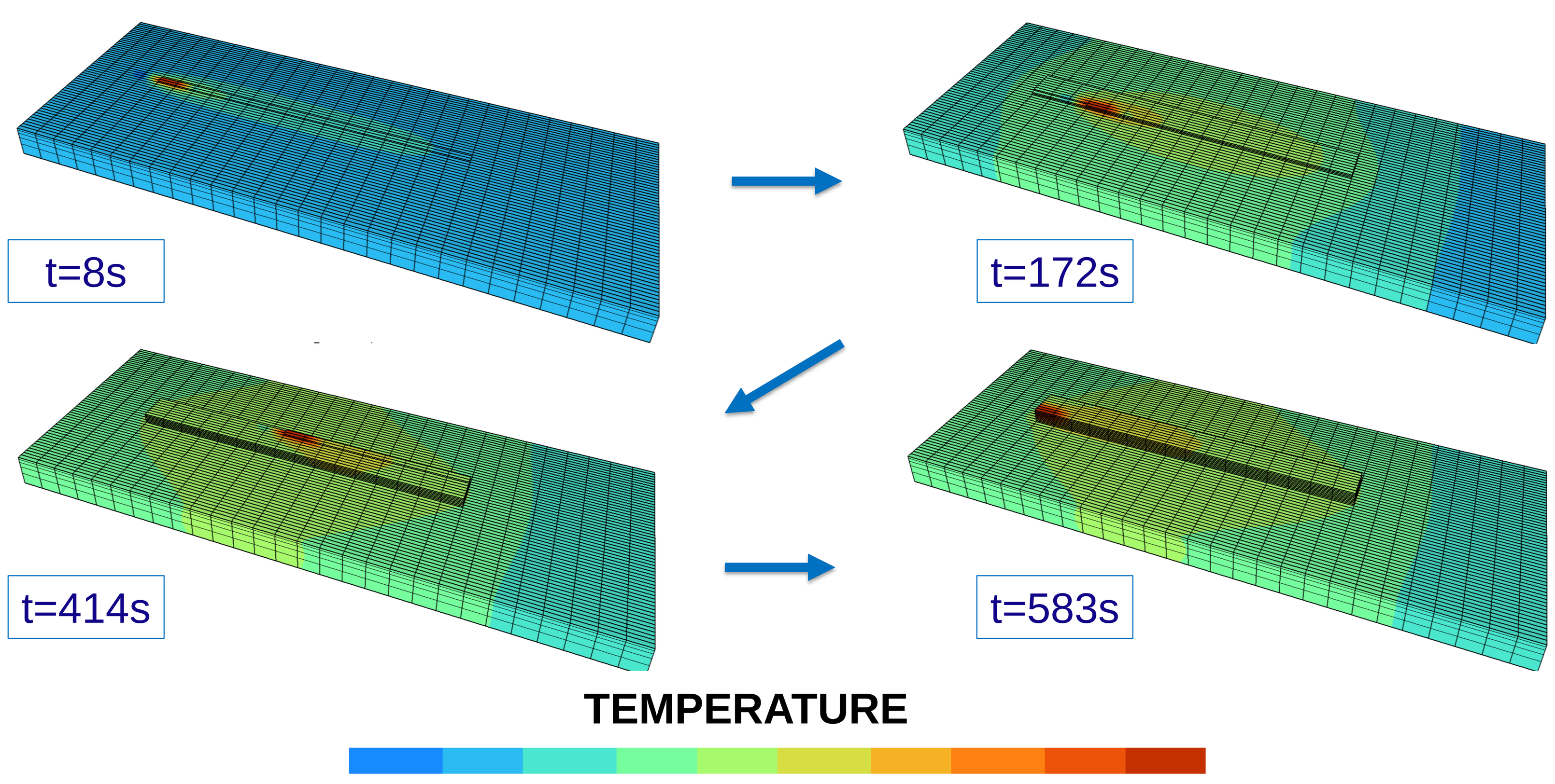
- **Finite elements and boundary conditions** (convection/radiation/laser heat flux) are all created at the **start of the simulation** but only enter the computation after their activation (**born-dead elements**).
- **Sets** of finite elements or boundary conditions are **activated/deactivated** based on the **current laser position/mesh geometry** (see figure bellow).
- The method used is **adapted from** the deactivation of elements and boundary conditions used in **crack propagation [2].**

Computation of new active mesh and boundary conditions



1. Known configuration at time t.
2. Computation of laser position at time t + Δt .
3. Activation of finite elements based on the new laser position.
4. Deactivation of boundary conditions and heat flux based on the new mesh geometry and laser position.
5. Activation of boundary conditions and heat flux based on the new mesh geometry and laser position.

Time evolution of the process



References

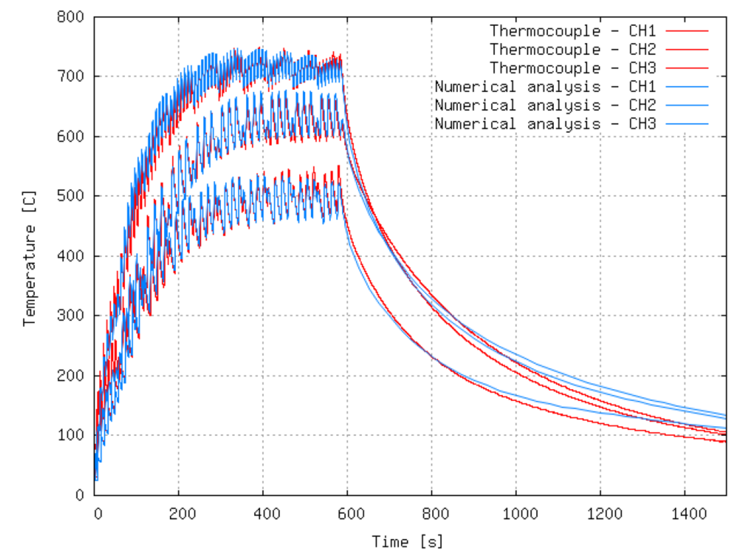
[1] J.-P. Ponthot, "Unified stress update algorithms for the numerical simulation of large deformation elasto-plastic and elasto-viscoplastic processes", International Journal of Plasticity. 18 (2002) 91-126.

[2] J.-P. Ponthot, R. Boman, P.-P. Jeunechamps, L. Papeleux, G. Deliége, "An implicit erosion algorithm for the numerical simulation of metallic and composite materials submitted to high strain rate", Proceedings of the Indian National Science Academy. 79/4 (2013) 519-528

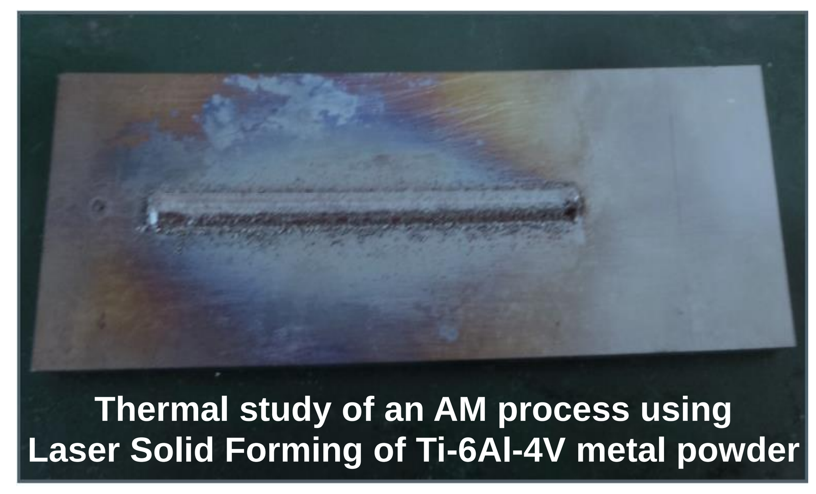
[3] M. Chiumenti, X. Lin, M. Cervera, W. Lei, Y. Zheng, W. Huang, "Numerical simulation and experimental calibration of Additive Manufacturing by blown powder technology. Part I: thermal analysis", Rapid Prototyping Journal 23 (2) (2017) 448–463.

Reference results (Chiumenti et al.[3]–COMET [4])

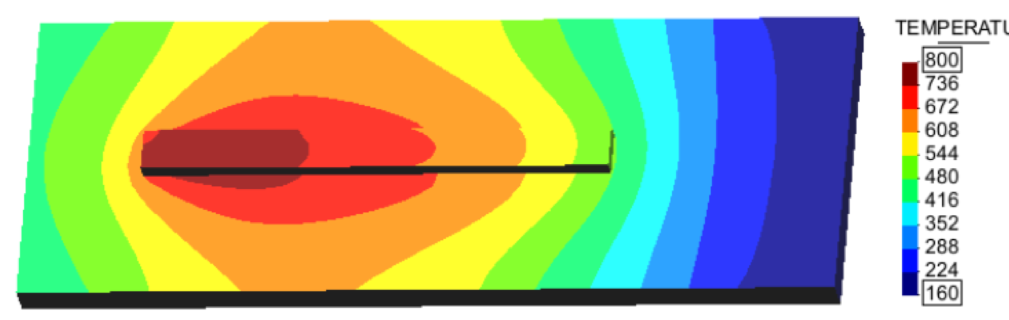
Experimental and numerical temperature evolution [3]



Experimental piece after process [3]



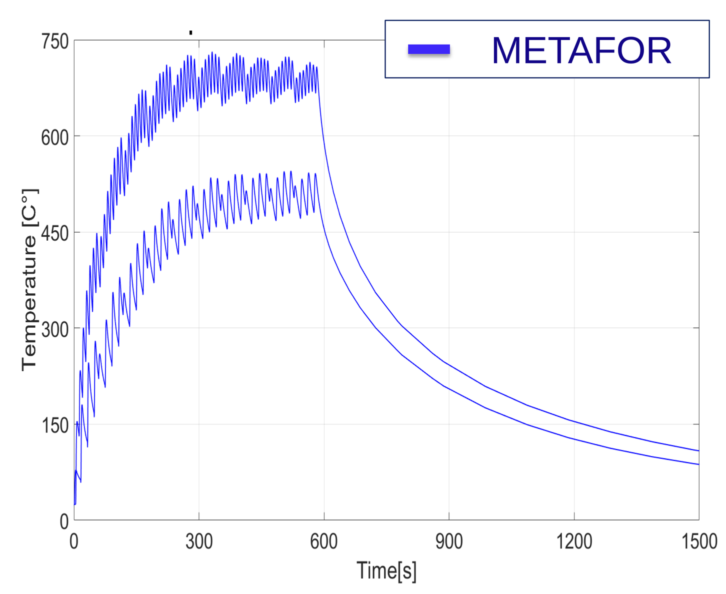
Final temperature distribution: COMET [3]



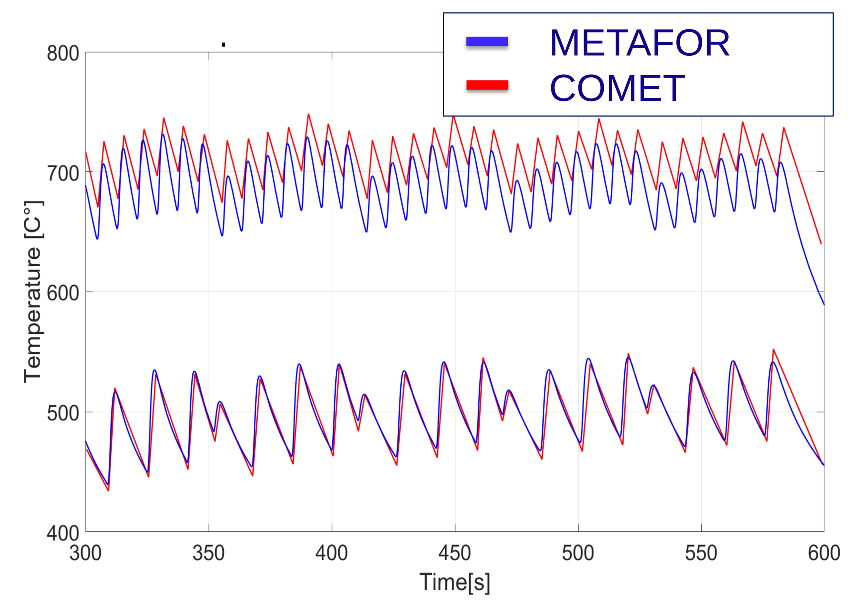
- **Good agreement between the experimental and numerical evolution of the temperature.**
- **Good agreement between the final temperature distribution and the experimentally observed oxidation zone .**

Our results (Metafor)

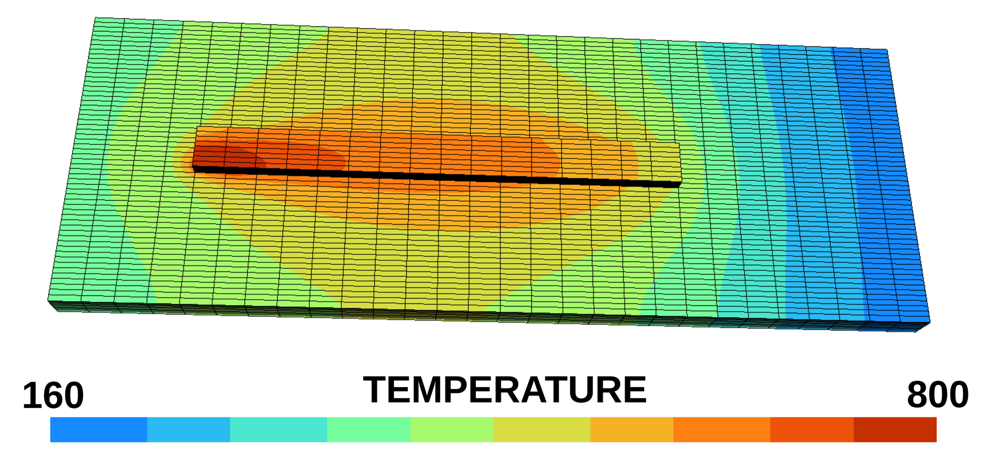
Temperature evolution at 2 thermocouples: Metafor



Temperature evolution at 2 Thermocouples: Metafor/COMET



Final temperature distribution: Metafor



- **Good agreement of the temperature evolution between COMET and Metafor.**
- **Both Metafor and COMET could predict the experimental oxidation zone.**

Good agreement between the results obtained by COMET and Metafor.

Plan for future research

- **Optimize Metafor** for the modeling of Additive Manufacturing:
  - The method is currently **not CPU-efficient**. Indeed, since the elements are **activated by "sets"** in Metafor, it requires the creation of a **very high number of sets (1 set for each boundary condition/element).** The software was not built to efficiently handle such a high number of sets.
  - Create a more automated activation/deactivation technique within a single set of elements.

- Improve of the **FEM modeling of the mesh/geometry** for Additive Manufacturing:
  - **Implement X-FEM to model the geometry of additive manufacturing processes** to remove the constraint of a very fine mesh imposed by the layer height without lost of accuracy:

X-FEM for AM: