High-fidelity thermal finite-element analysis of additive manufacturing by blown powder

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1 A FE framework is useful to improve the industrial design of AM processes

Additive Manufacturing (AM) is being increasingly implemented in many industrial sectors, thanks to recent advances in reduction of costs and production times. As a result, Finite-Element Analysis (FEA) is strongly demanded to support their design.

Different AM technologies have already been modelled with FEA, using previous experience in modelling welding processes [1, 3]. Here, *blown powder* technologies for metal components are addressed, described in Figure 1.

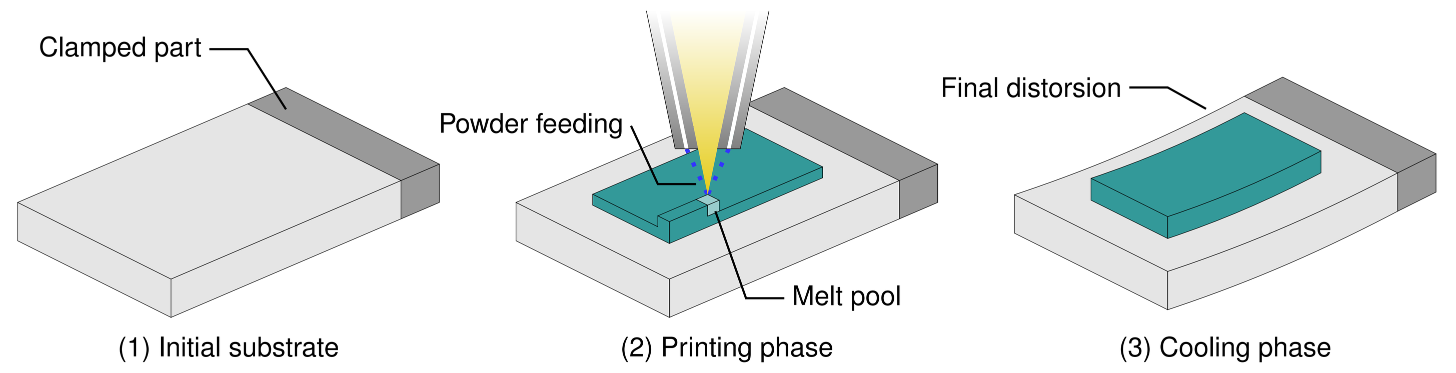

Figure 1: AM process by *blown powder* of a sample. Metal powder is blown coaxially to a laser beam that melts the particles on a substrate to form a metallurgical bond when cooled.

The main objective of this work is to design a FE framework for the thermal analysis of these processes. An exhaustive experimental campaign for the calibration and sensitivity analysis of the model is carried out using a Laser Solid Forming (LSF) machine and Ti-6Al-4V powder for the samples (Figures 2, 3). The predictive capabilities of the model can be used to design scanning patterns that minimize distortions, residual stresses and hot-cracking risk.

Figure 2: LSF machine and detail of powder feeding nozzle.

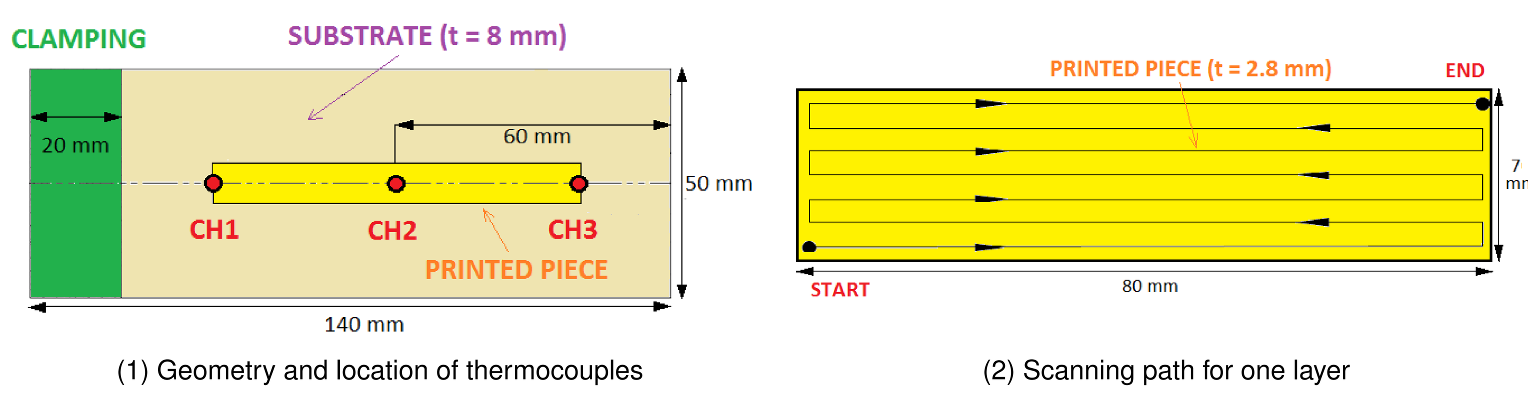

Figure 3: Detailed description of the experimental setting reproduced numerically. The finite-element mesh consisted of structured hexahedra.

2 A FE activation technology is used to reproduce the printing sequence

The numerical model adopts an apropos FE activation technology [2], that reproduces the same scanning pattern set for the numerical control system of the AM machine. This pattern consists of a complex sequence of polylines, used to define the contour of the component, and hatches patterns to fill the inner section (Figure 3.2).

Both the heating and cooling phases of the process are governed by the equation of conservation of energy. The heat source is the energy input from the laser beam, that moves according to the user-defined scanning path. The laser is very concentrated and melts the surronding particles (*melt pool*).

The energy input is transferred from the melt pool to the remaining body through heat conduction. Heat conduction drives the heat loss through the clamped material surface (dark gray in Figure 1). Elsewhere, heat convection and radiation govern the heat loss with the surrounding air.

3 The numerical model remarkably agrees with the experimental data

The sample used for the validation of the FE model is described in Figure 3. Calibration results and the most relevant sensitivity analyses are detailed in Figures 4 and 5, and 6.

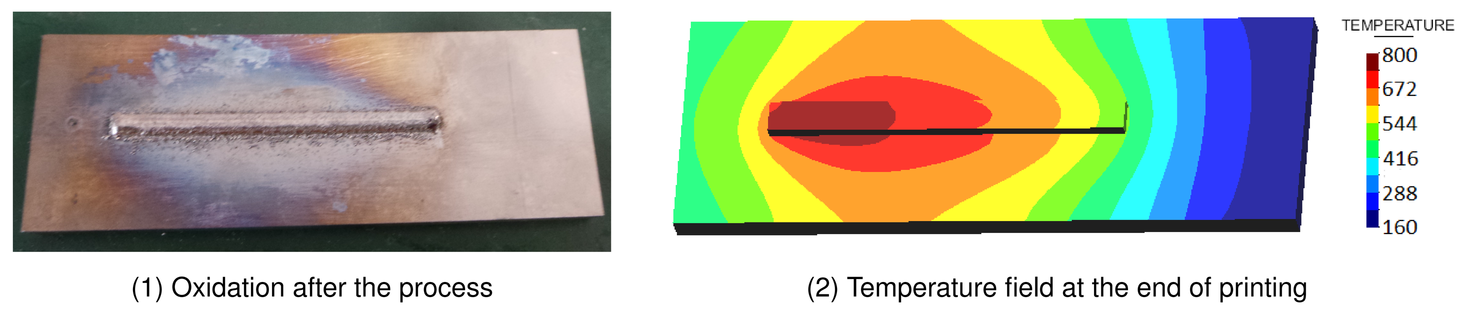

Figure 4: The model agrees with the oxidated pattern of the sample.

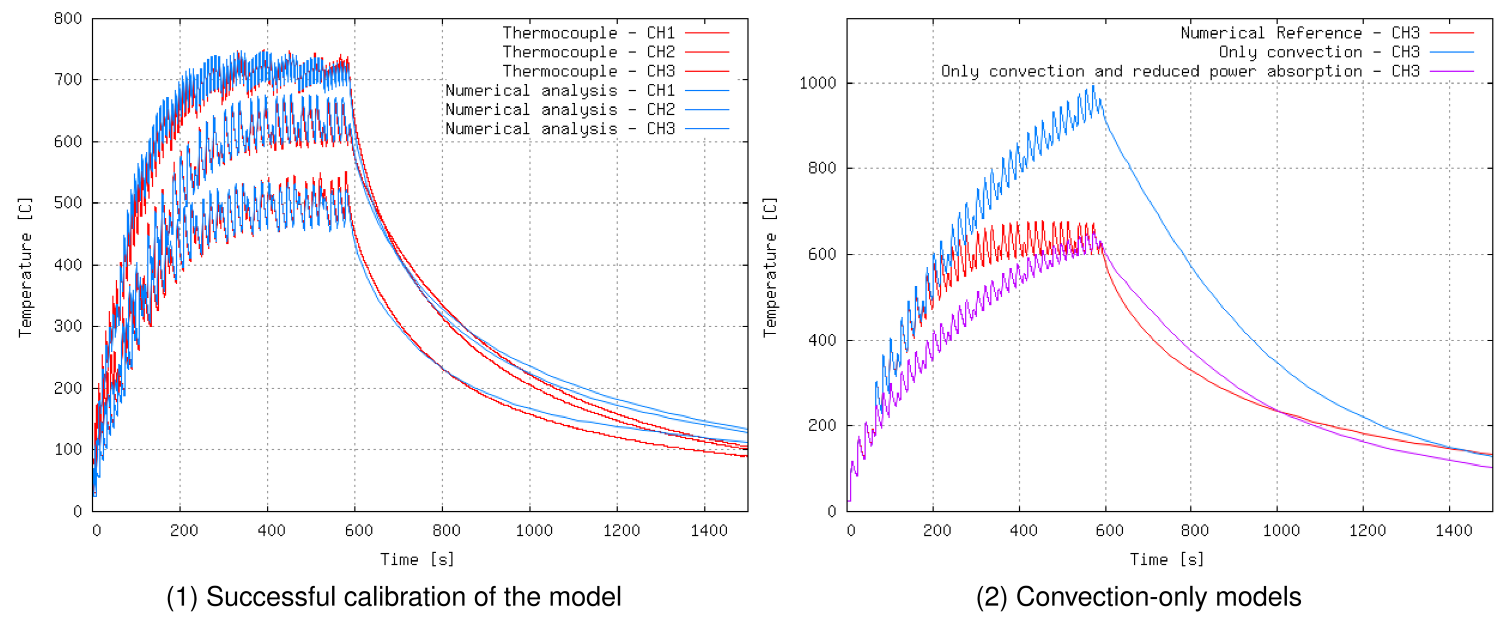

Figure 5: Radiation is the main dissipation mechanism and cannot be neglected, convection-only models cannot match the experimental data.

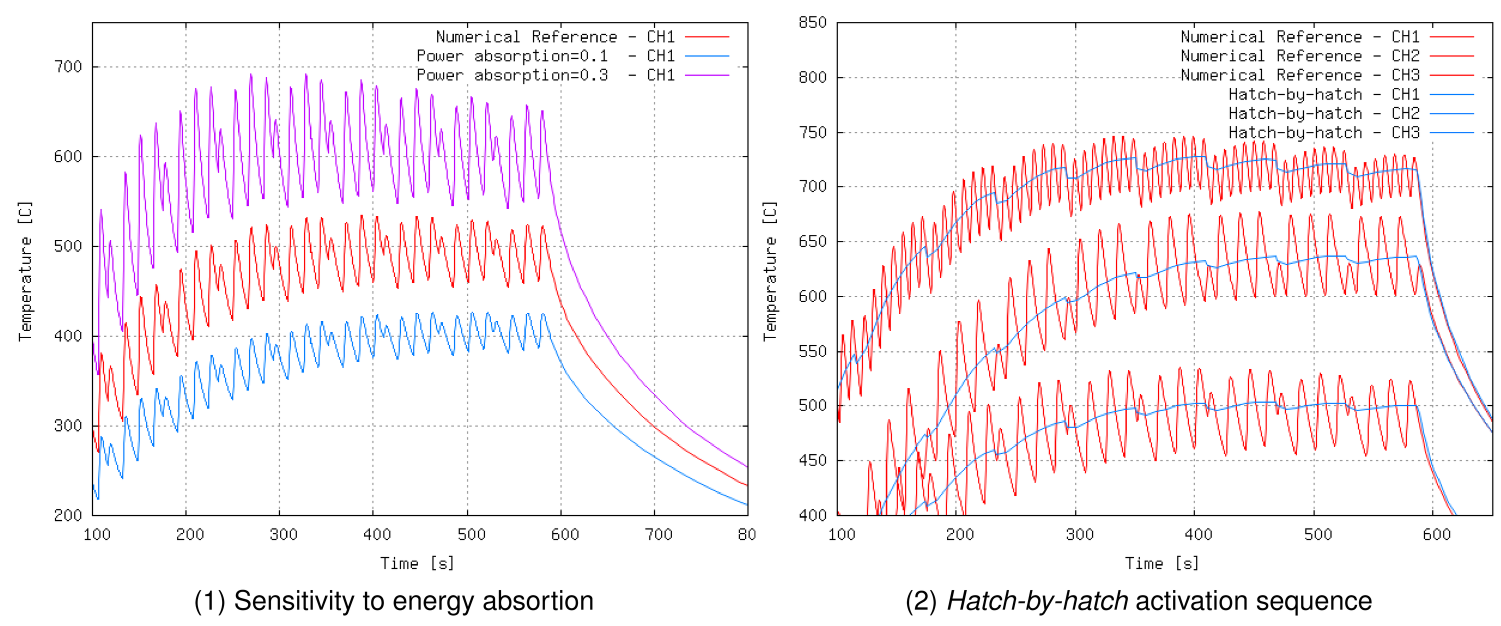

Figure 6: The model is very sensitive to the energy absorption parameter (efficiency of the power input). A *hatch-by-hatch* activation sequence reduces the computational time, but only recovers an average response.

4 Conclusions and further work

- A numerical simulation and experimental calibration for the thermal analysis of additive manufacturing by blown powder technology has been carried out with successful results.
- Heat radiation through the surrounding environment is the main mechanism of heat dissipation.
- The model is highly sensitive to the energy absorption parameter and the simulation time can be sped-up with a *hatch-by-hatch* or *layer-by-layer* activation sequence, but only an average response is obtained and the local thermal history is lost.
- Further work aims to deal with the computational cost of the simulation with a simplified model or a parallel implementation.

5 Main references

[1] Chiumenti, M., Cervera, M., Dialami, N., Wu, B., Li, J., and Agelet de Saracibar, C., Numerical modeling of the electron beam welding and its experimental validation. *Submitted to Rapid Prototyping Journal* (2015).

[2] Chiumenti, M., Lin, X., Cervera, M., Lei, W., Zheng, Y., and Huang, W., Numerical simulation and experimental calibration of Additive Manufacturing by blown powder technology. Part I: thermal analysis. *Submitted to Rapid Prototyping Journal* (2015).

[3] Chiumenti, M., Cervera, M., Salmi, A., Agelet de Saracibar, C., Dialami, N., and Matsui, K., Finite element modeling of multi-pass welding and shaped metal deposition process. *Comp. Meth. in App. Mech. and Eng.* (2010) 199:2343–2359.

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