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Modelling of melt cast cooling and solidification processes for explosives

Peggy LAMY-BRACQ, Christophe COULOUARN

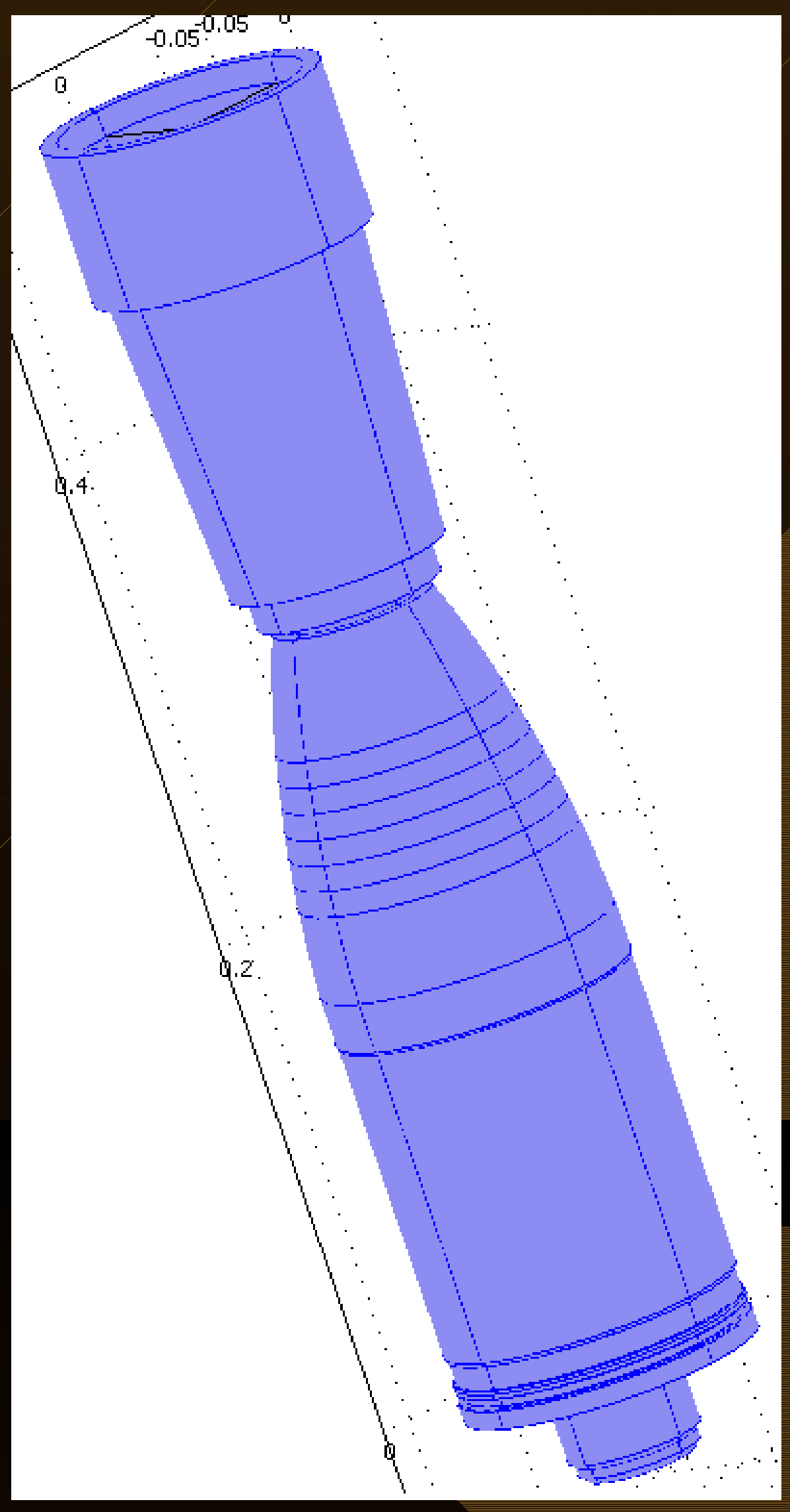
Nexter Munitions

The search for high-energy but low-sensitivity explosives has been the focus of many studies. It has been found that the use of cyclo-trimethylene-trinitramine (RDX) or cyclo-tetramethylene-tetranitramine (HMX) can maximize the energy of the explosive while minimizing its sensitivity. However, the preparation and processing of such explosives is a major challenge for military applications.

Melt casting and mechanical pressing are two of the most used approaches for explosives production. Of the two, melt casting is more economical for large-scale filling in munitions applications. A large amount of charge can be cast, even with very special shape. Explosives melt casting has traditionally been based on a trial-and-error approach. Further process and product improvements call for the development of a comprehensive numerical model that allow a systematic study of the melt casting process parameters and offer a better understanding of the physical mechanisms involved. The numerical modelling and simulation presented here are used to determine optimized casting parameters. High quality explosives can not be produced without well-controlled casting parameters.

Problems to be solved

- Product non-uniformity
- Porosity and cavities
- Void formation
- Shrinkage
- Cracks and micro-defects



Model

- Heat transfer by conduction equation:

$$\rho C_p \frac{\partial T}{\partial t} - \nabla(\lambda \nabla T) = Q$$

- Incompressible Navier-Stokes:

$$\rho \frac{\partial \vec{u}}{\partial t} - \nabla \mu\left(\nabla \vec{u} + (\nabla \vec{u})^T\right) + \rho\left(\vec{u}\nabla\right)\vec{u} + \nabla p = \vec{F}$$

$$\frac{\partial \rho}{\partial t} + \nabla\left(\rho \vec{u}\right) = 0$$

- Phase change during solidification:

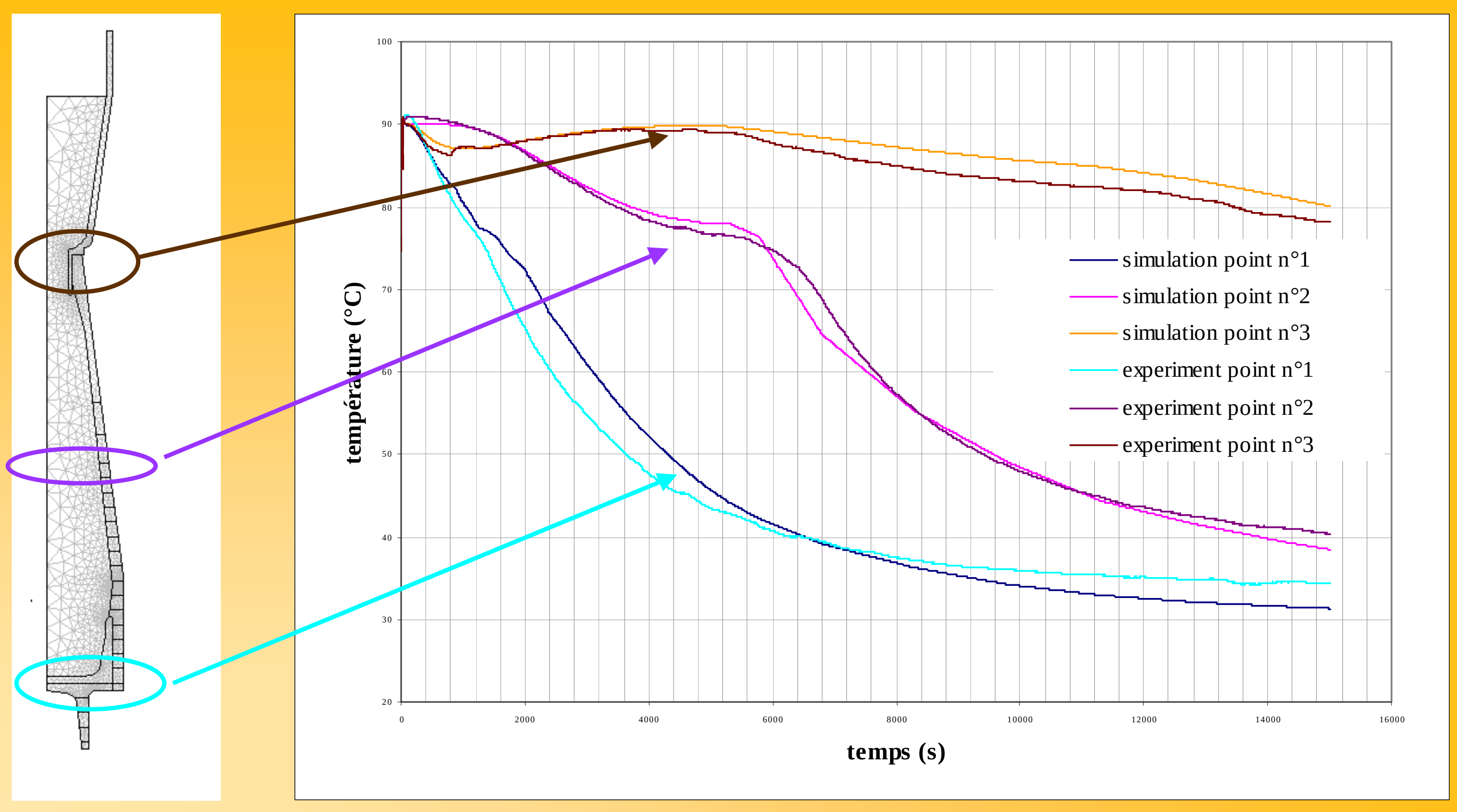
$$C_p = C_{p\,solide} + \frac{\Delta H_f}{T_f}(\,flc2hs(T - T_f, 1)) + \Delta H_f .\exp\left(-\frac{(T - T_f)^2}{\sqrt{\pi}}\right)$$

Inputs for the Model

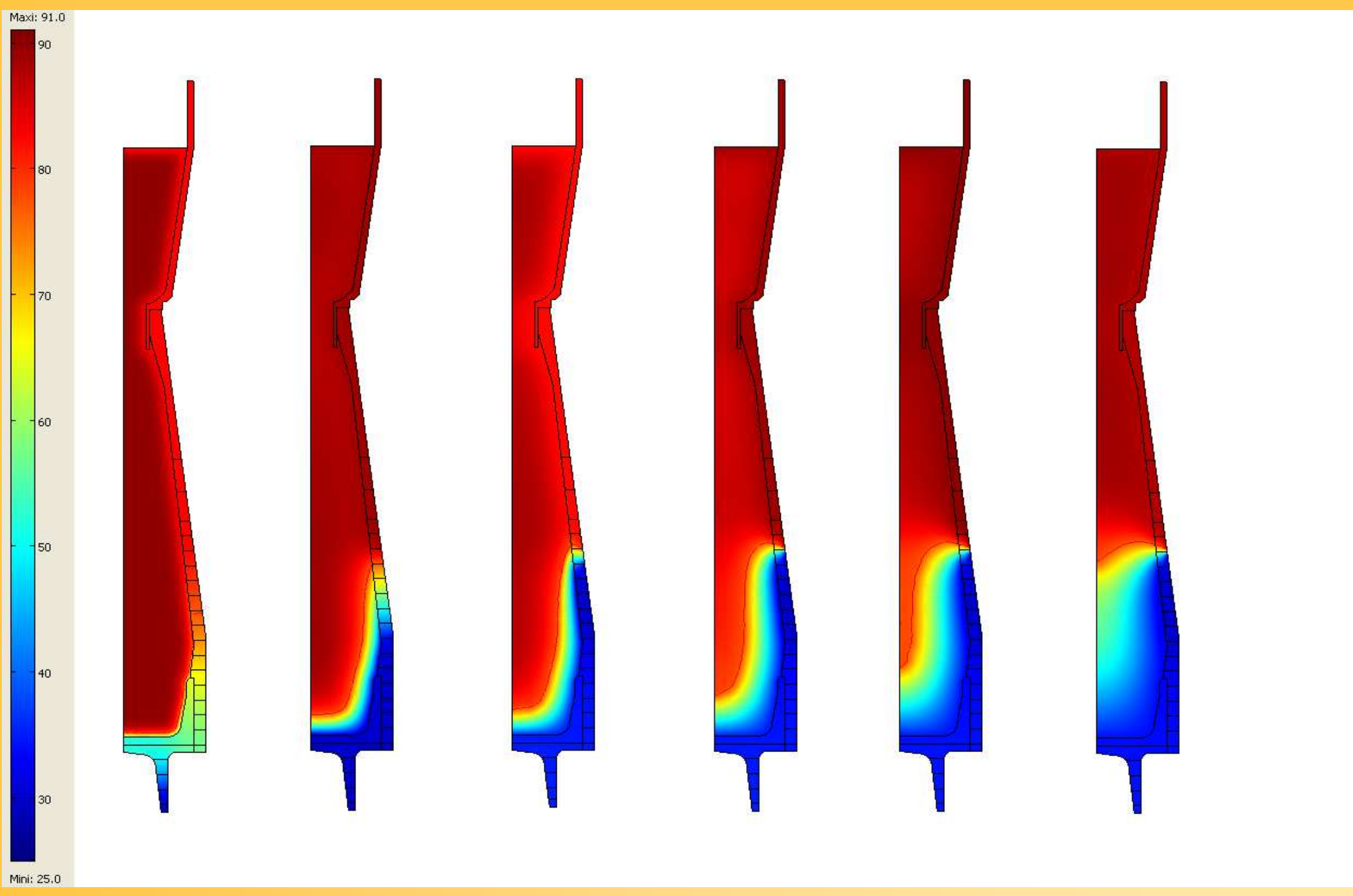
- Explosive properties:
  - Density: ρ
  - Melting point: T_f
  - Latent heat of solidification: ΔH_l
  - Thermal conductivity: k
  - Thermal expansion coefficient: α
  - Viscosity: η
- Conditions:
  - Initial temperature of metal and explosive: T_0
  - Ambiant air temperature: T_{ext}
  - Cooling conditions: conduction, free convection, forced convection

Results of COMSOL 3.4 simulation:

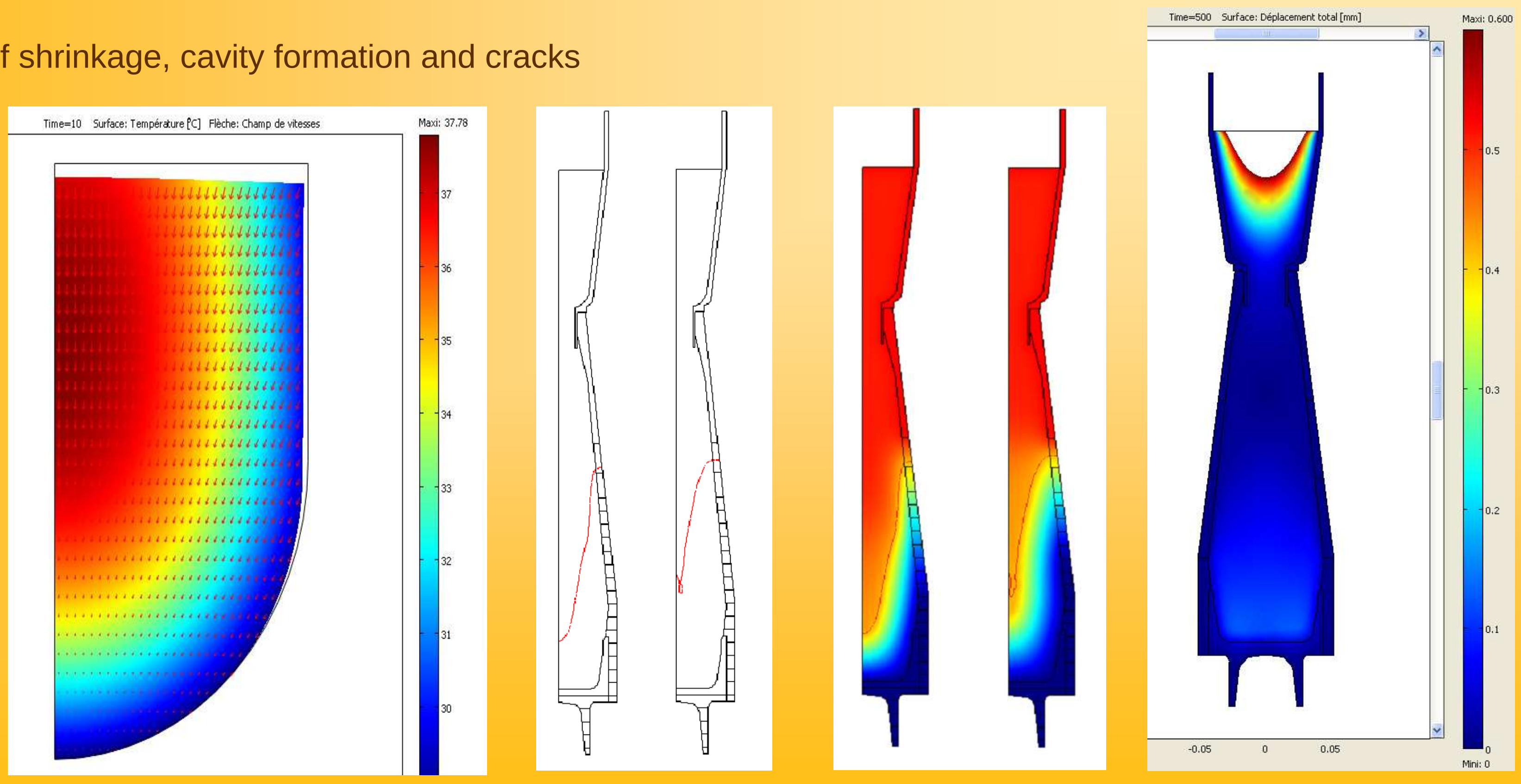
- Validation of the model : comparison between measured temperature and simulated temperature



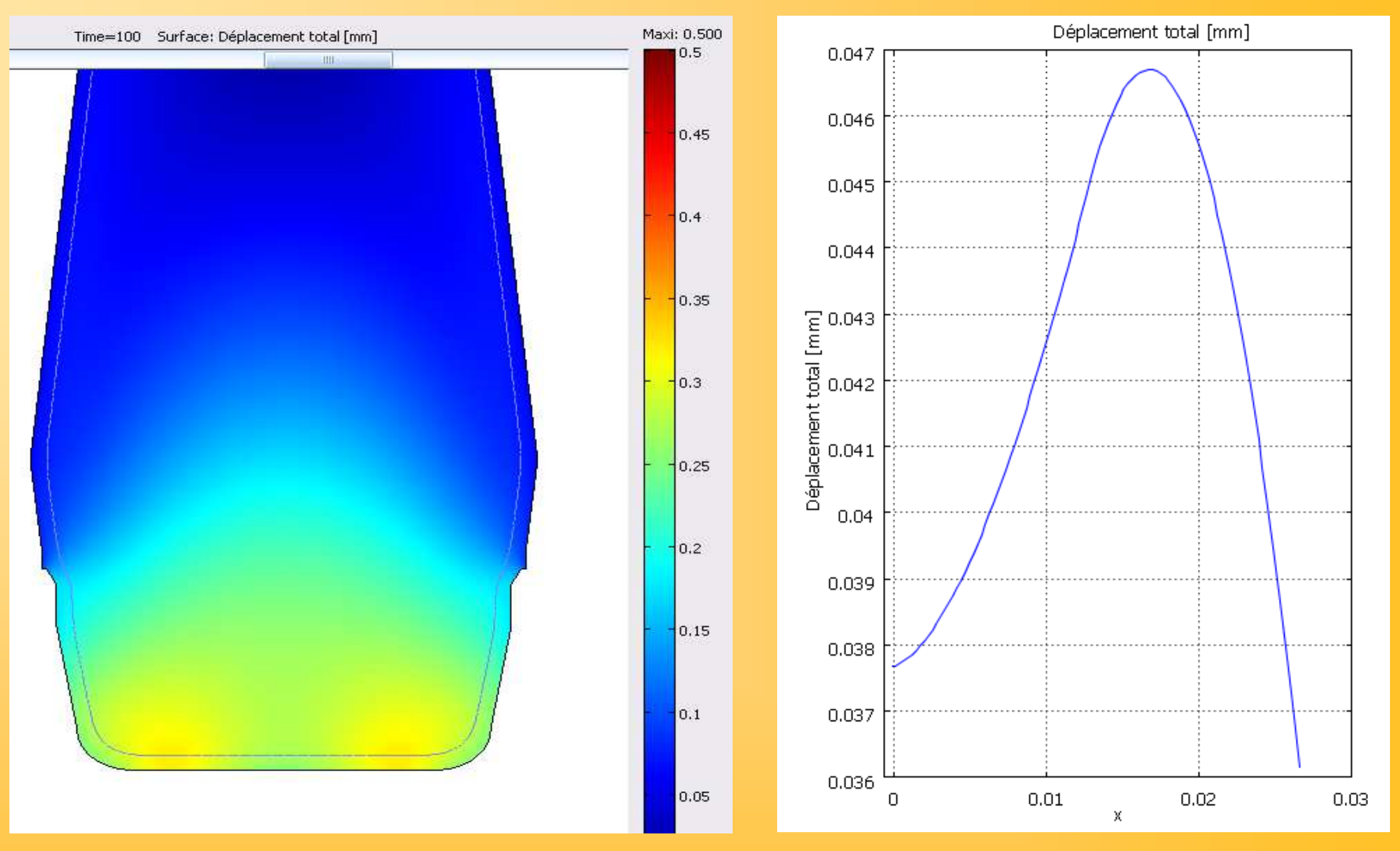
- Solidification front evolution versus time is observed to determine the best cooling conditions



- Visualisation of shrinkage, cavity formation and cracks



- Visualisation of stress/strain and shrinkage



➔ This new model is a cost and time-effective tool to optimize the process parameters