Simulation of the Cooling and Phase Change of a Melt-Cast Explosive

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Introduction:

Numerical modeling of melt-casting is becoming a popular tool for the defense industry. Our work focuses on the solidification process and the development of thermal stresses during cooling in a Composition B melt. Innovative attempts are made to model defects such as gap formation due to volume changes and investigate the role played by mold adhesion.

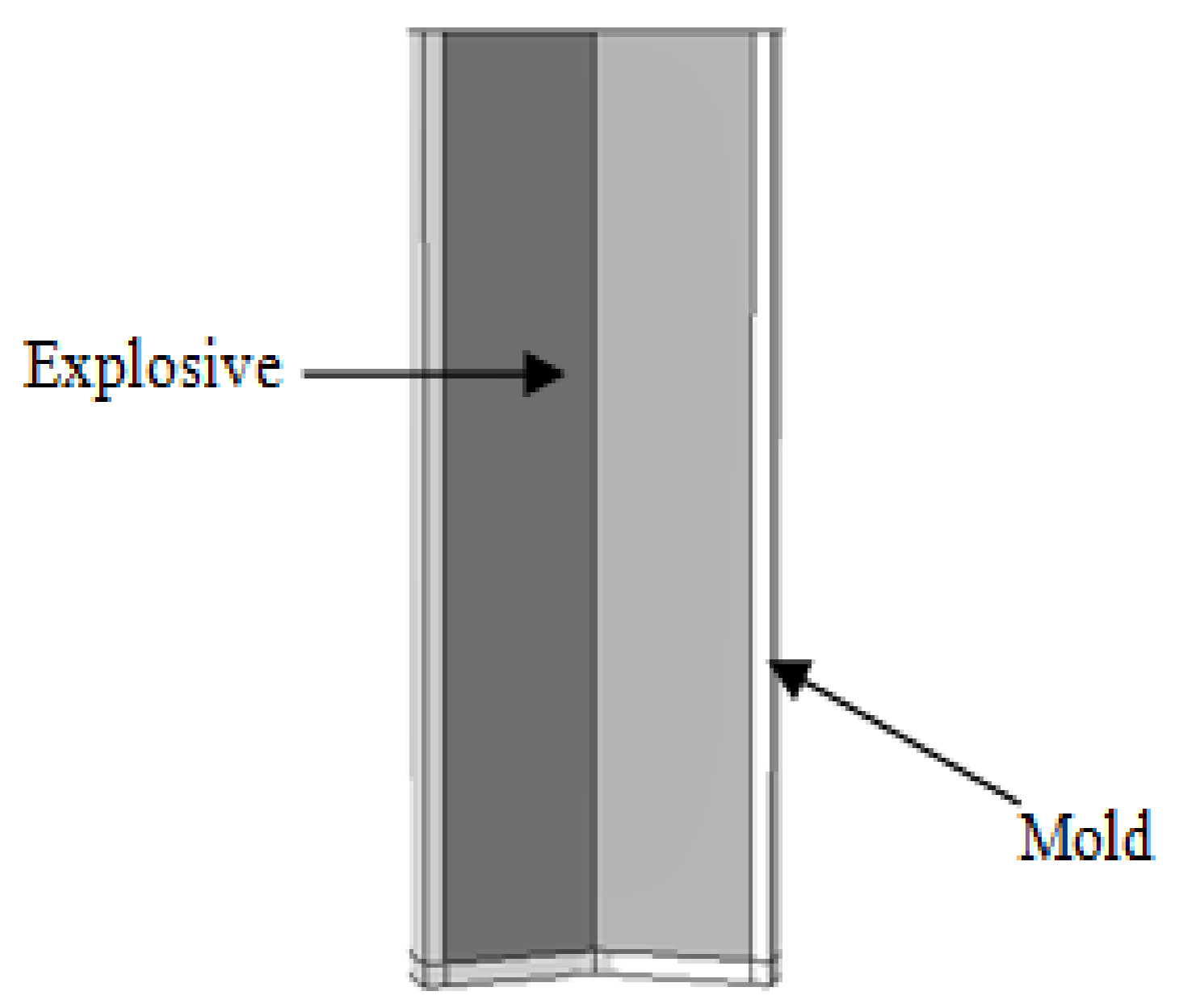


Figure 1. Cylinder casting

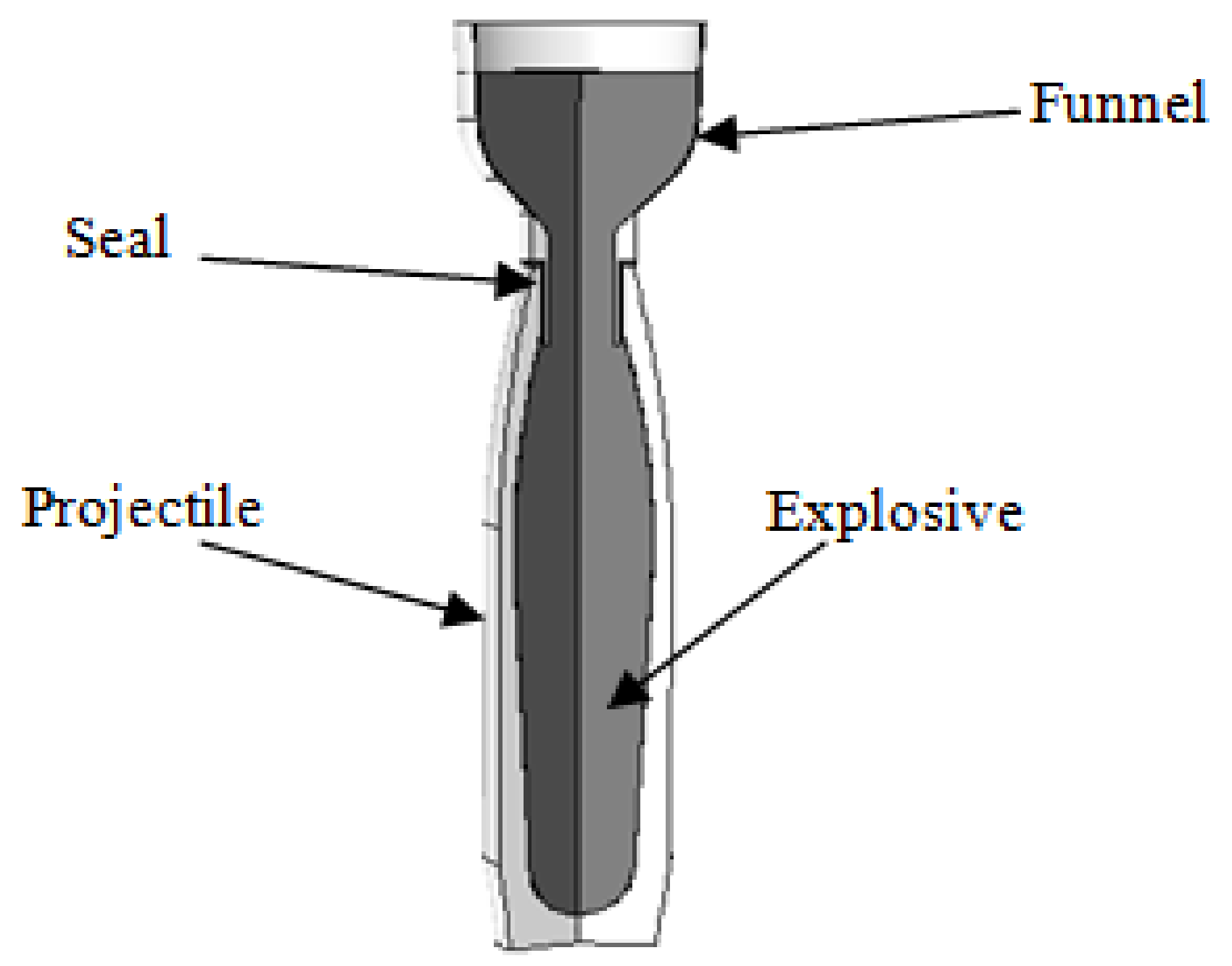


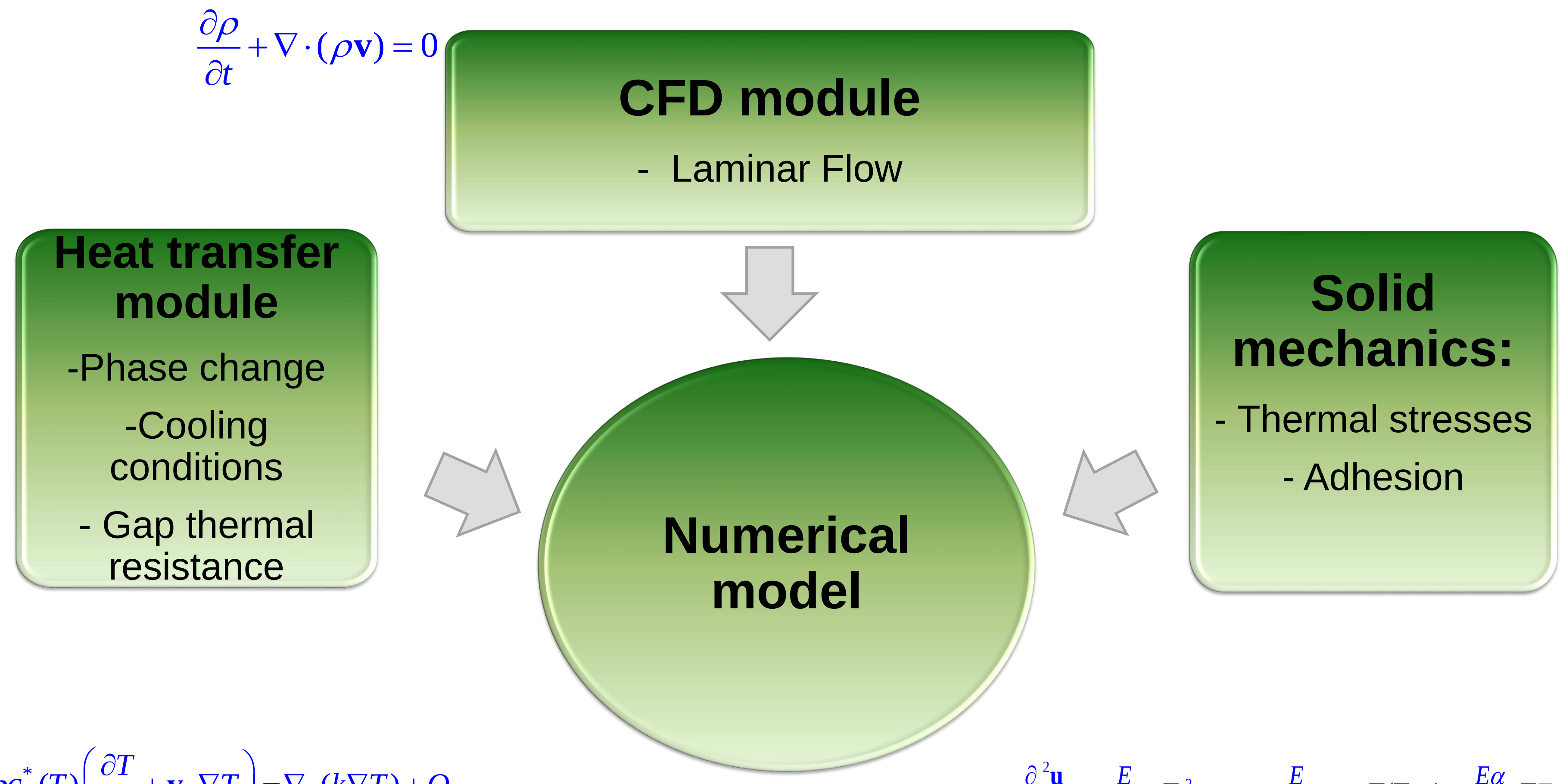
Figure 2. 105 mm projectile

Computational Methods:

Solidification is based on an enthalpy method.

$$\rho(\frac{\partial \mathbf{v}}{\partial t}+\mathbf{v}\cdot\nabla\mathbf{v})=-\nabla p+\mu\nabla^2\mathbf{v}+\rho\mathbf{g}+\frac{(1-f_l)^2}{f_l^3+q}C\mathbf{v}$$

$$\frac{\partial\rho}{\partial t}+\nabla\cdot(\rho\mathbf{v})=0$$



CFD module
- Laminar Flow

Heat transfer module
-Phase change
-Cooling conditions
- Gap thermal resistance

Numerical model

Solid mechanics:
- Thermal stresses
- Adhesion

$$\rho c_p^*(T)\left(\frac{\partial T}{\partial t}+\mathbf{v}\cdot\nabla T\right)=\nabla\cdot(k\nabla T)+Q$$

$$\rho\frac{\partial^2\mathbf{u}}{\partial t^2}=\frac{E}{2(1+n)}\nabla^2\mathbf{u}+\frac{E}{2(1+n)(1-2n)}\nabla(\nabla\cdot\mathbf{u})-\frac{E\alpha}{1-2n}\nabla T$$

- Specific boundary conditions applied to represent actual cooling conditions (e.g. partial water bath, probe heating, etc.);
- Incompressible, isotropic, Newtonian and thermo-elastic material;

Adhesion: cohesive zone model (CZM)

$$F_{adh}=\begin{cases} K_s u, & u<0 \square u_{\max}\le u_{peak} \\ (1-d)K_s u, & u_{peak}\le u_{\max}<u_{break} \\ 0, & u_{\max}\ge u_{break} \end{cases}$$

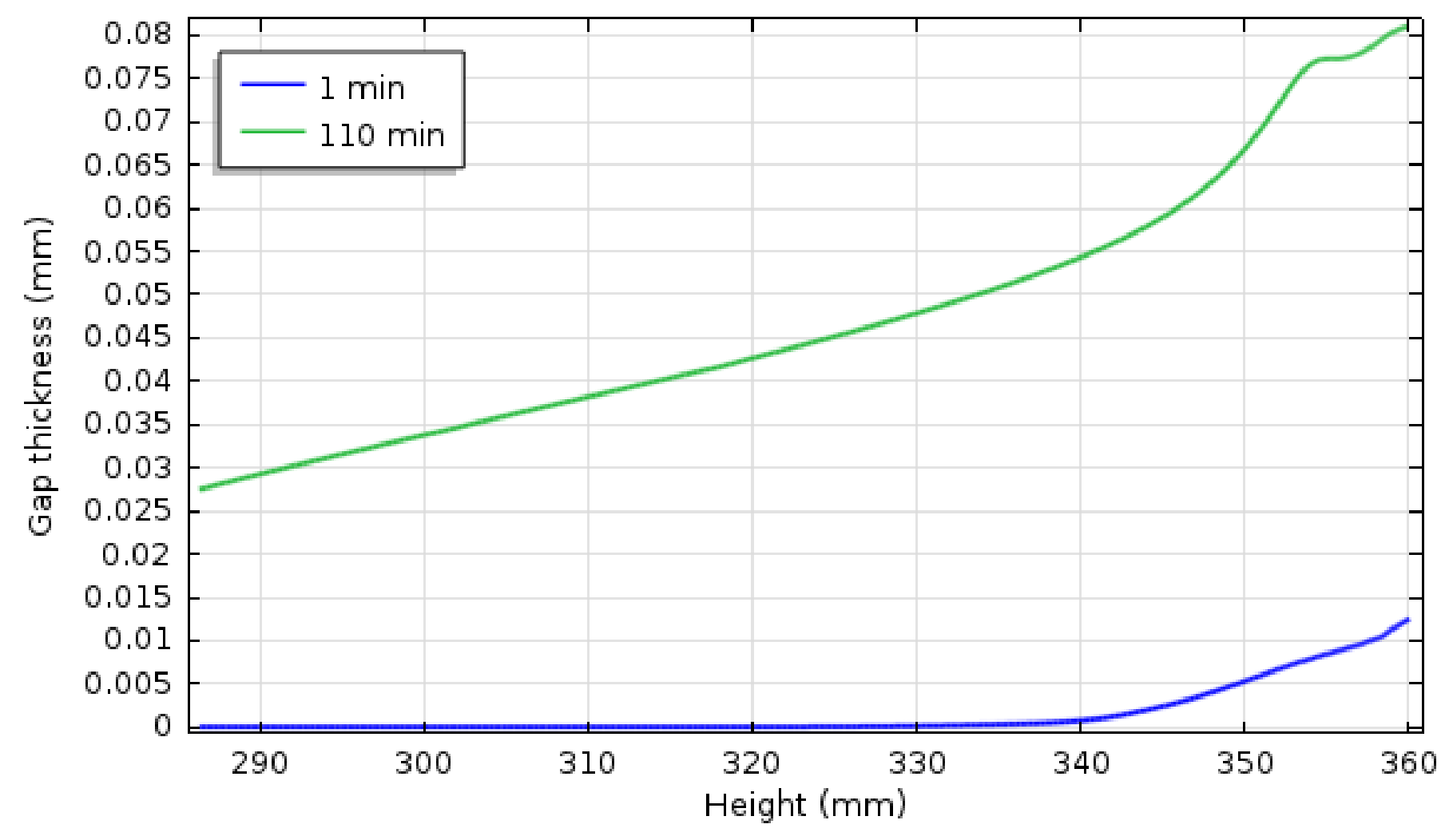


Figure 3. Gap formation in neck region of 105 mm caliber

Results:

- There is good agreement between experimental data and simulation results (Figure 4).
- Probe heating is used to avoid liquid pockets (which can lead to void formation).
- The onset of gap formation, convection effects and thermal stresses are well emulated.

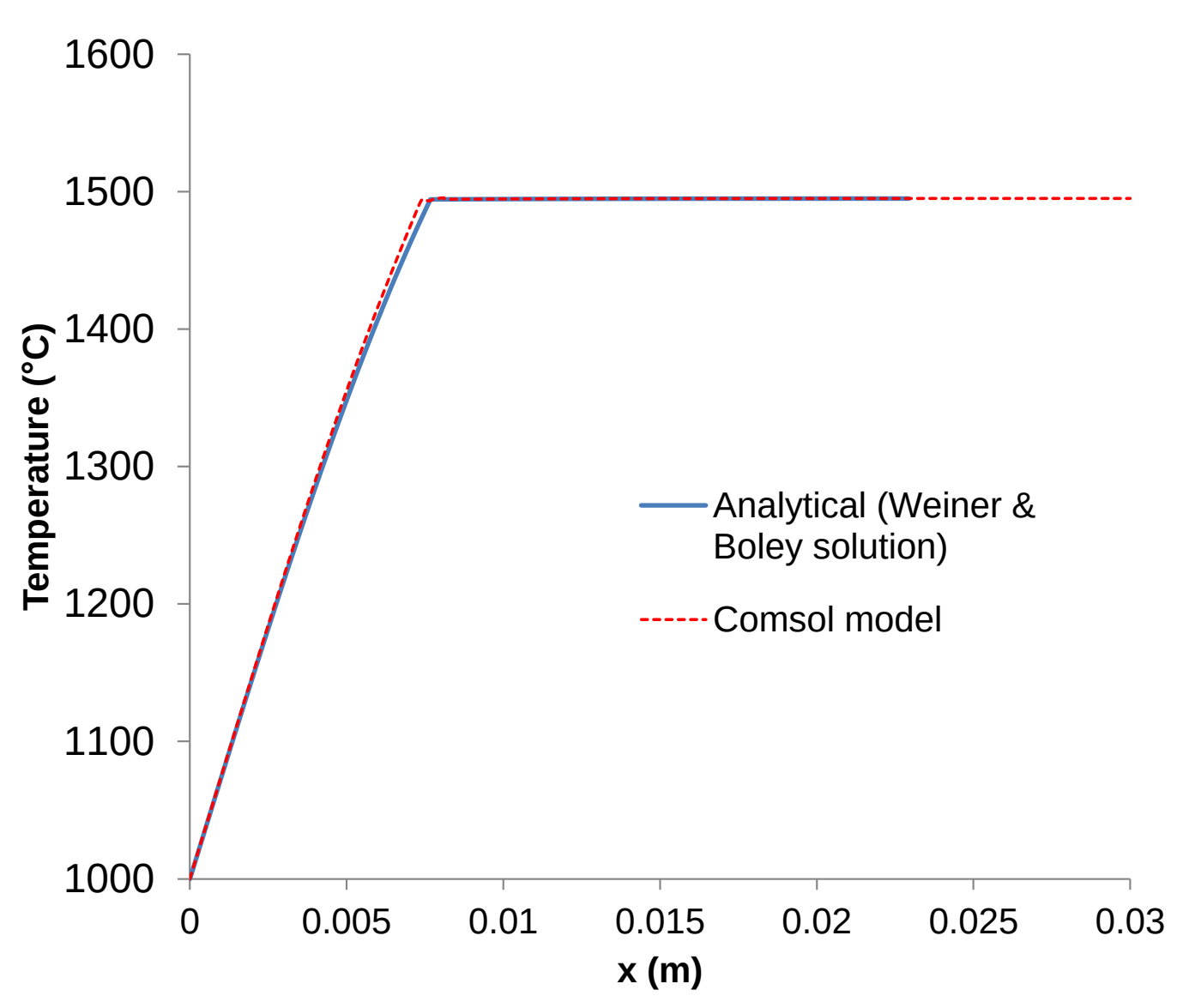


Figure 4. Model verification

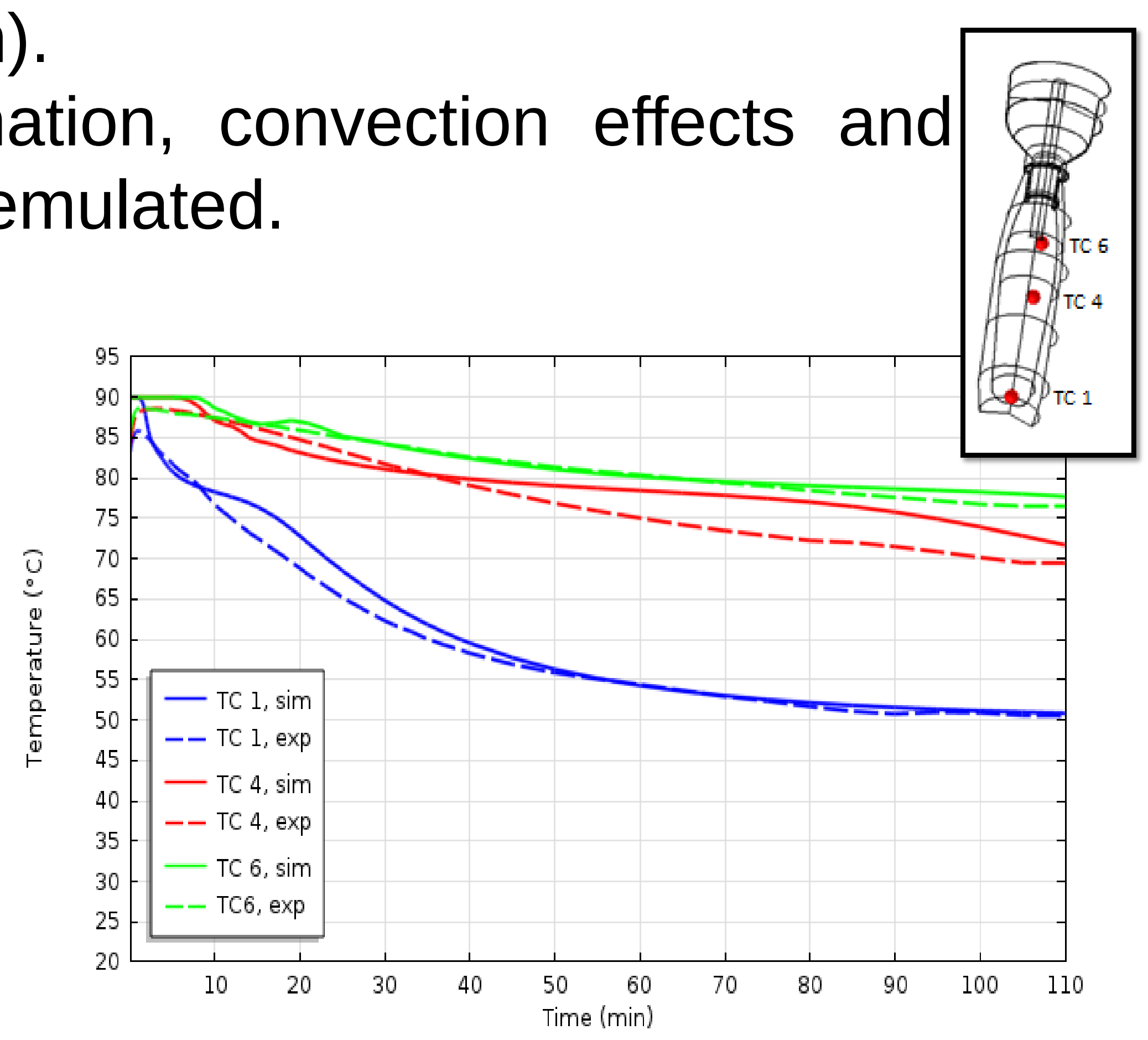


Figure 5. Experimental comparison

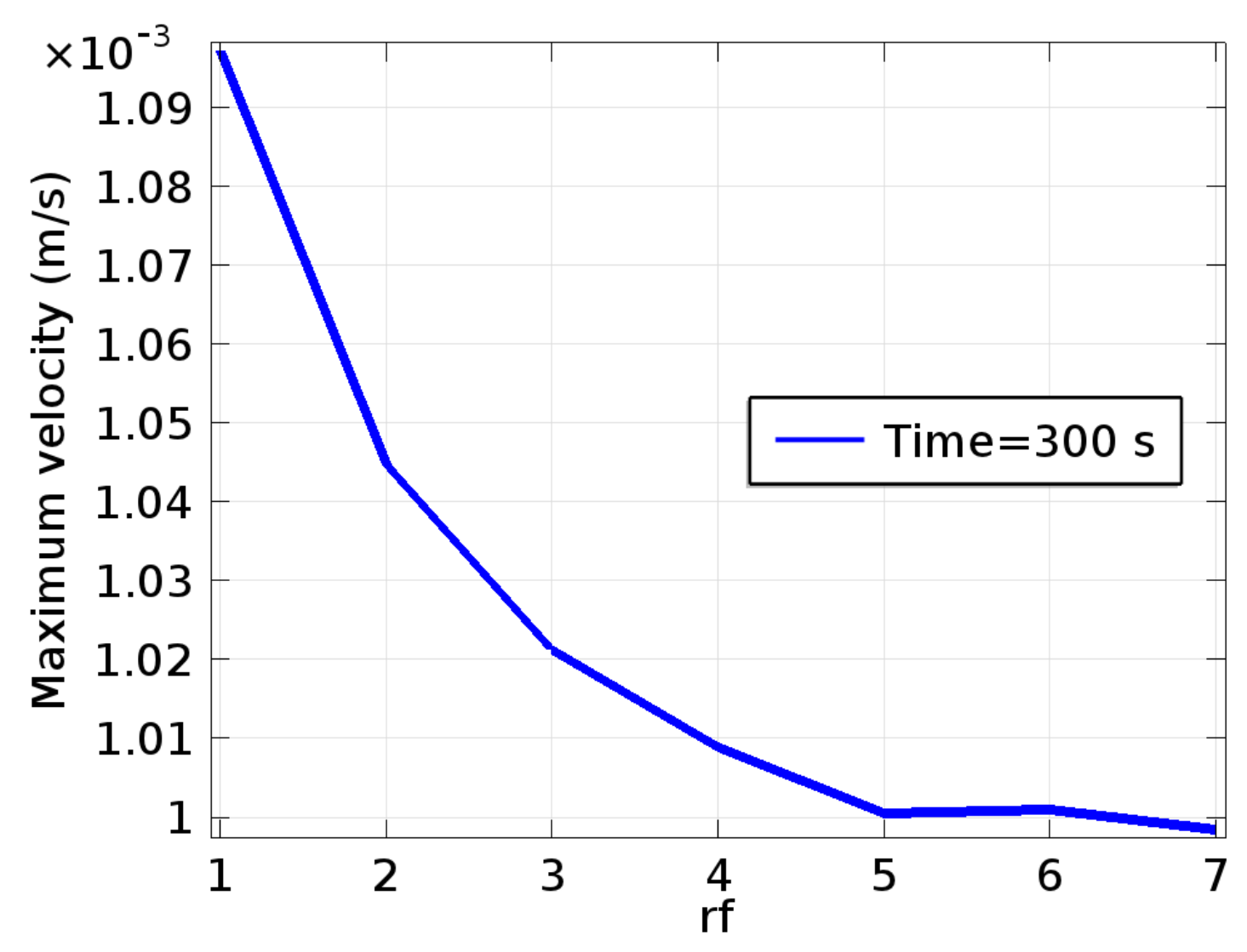


Figure 6. Mesh refinement – grid independency

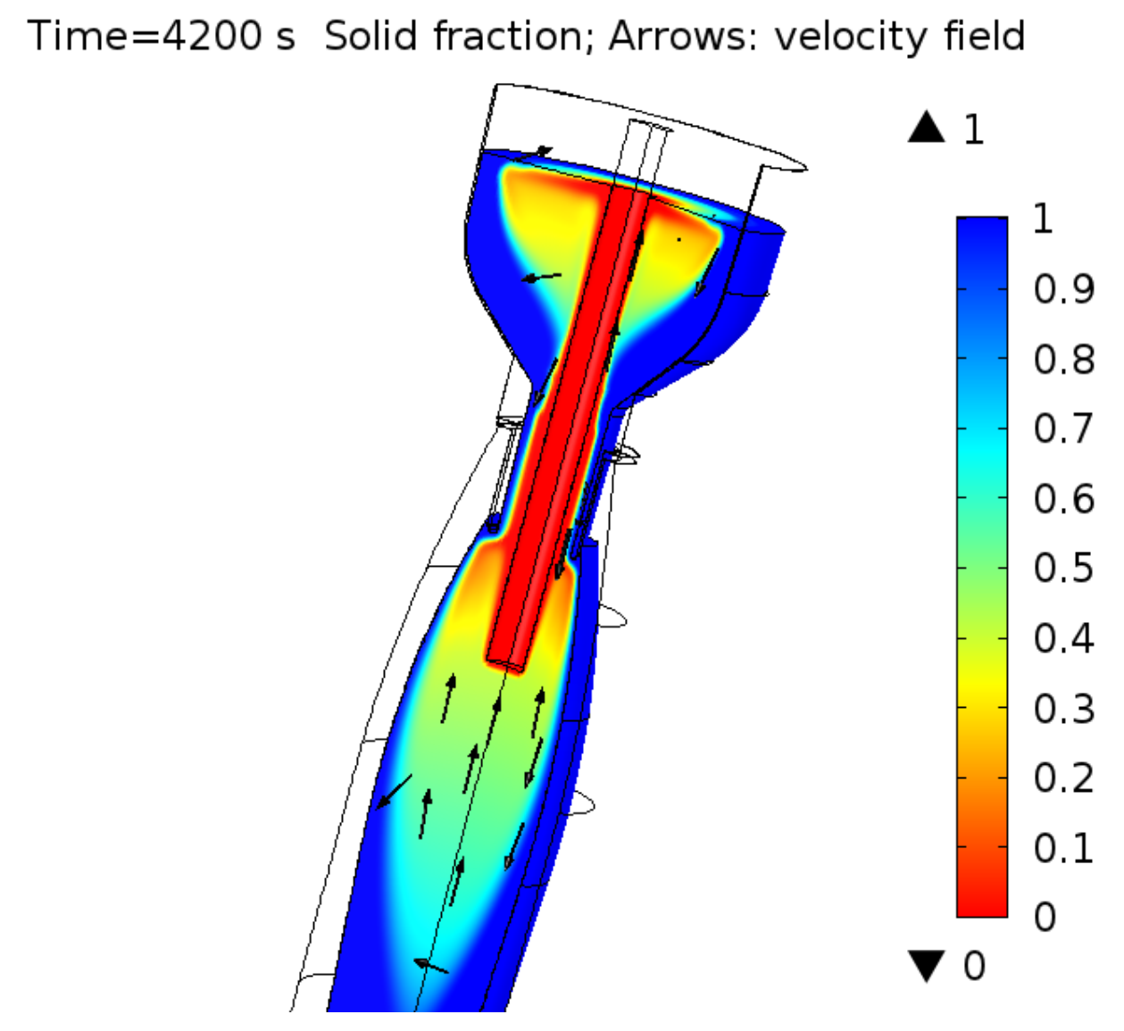


Figure 7. Solidification and melt convection

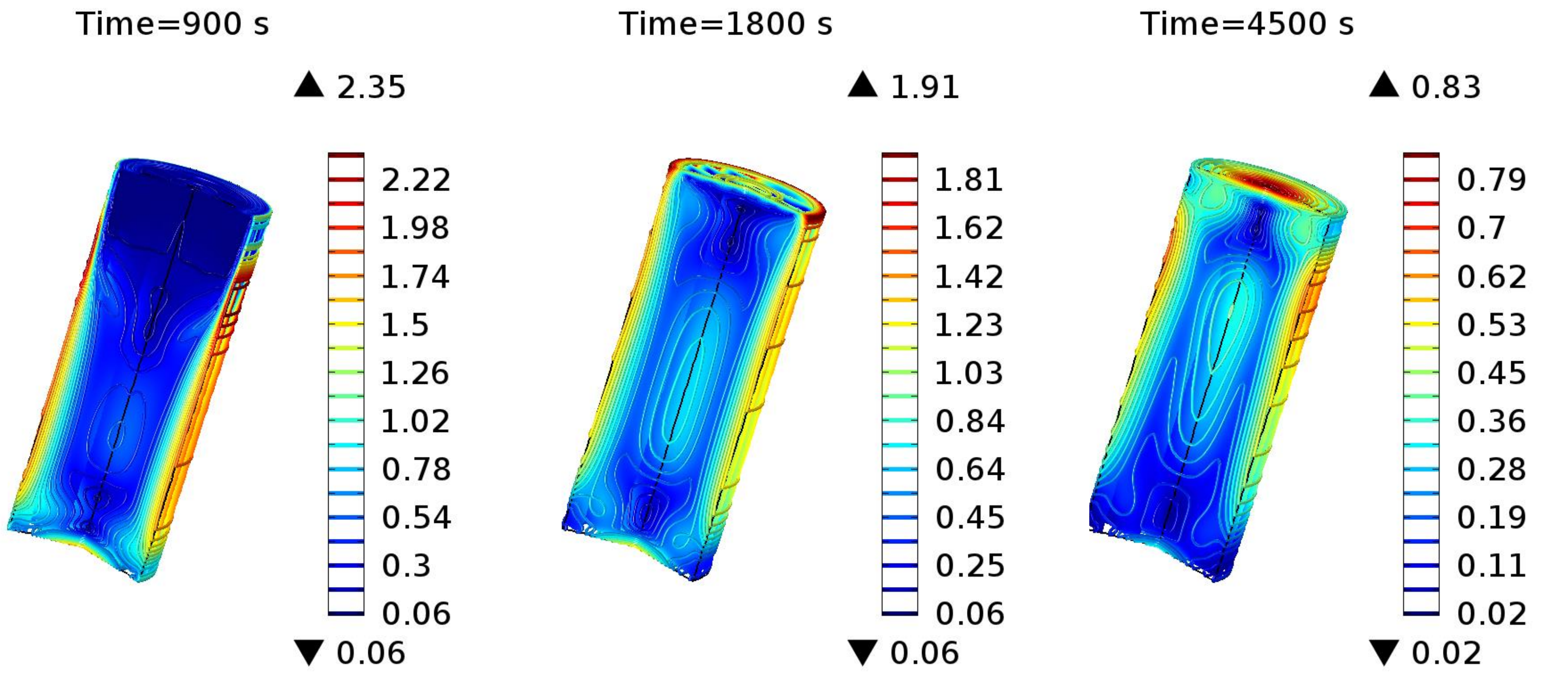


Figure 8. Thermal stresses evolution in cylinder casting (in MPa)

Conclusions:

The solidification model successfully integrates the phase change process together with associated thermal stresses during cooling. Potential sites for defects such as void or crack formation can be predicted and preliminary works regarding the inclusion of adhesion to the simulation are promising. Our research is now directed towards obtaining a better representation of real-time casting through more accurate material properties, better experimental data acquisition and improved solver efficiency in this highly non-linear model.

References:

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Excerpt from the Proceedings of the 2015 COMSOL Conference in Boston