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

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Abstract

Introduction
Numerical modeling of melt-casting is becoming a popular tool for the energetic materials and explosives industry. Compared to traditional metal casting, the cooling cycle for explosive melts is significantly longer because of their high Prandtl numbers [1]. Improving the casting is crucial and depends on optimizing the cooling cycle. Furthermore, it is well known that air entrapment or void formation due to shrinkage affect the product quality with respect to its combustion/detonation [2]. Through a comprehensive numerical tool, we aim to use COMSOL Multiphysics® software to model the solidification process and thermal stress development during cooling in a Composition B melt, including gap formation due to volume changes and the role played by adherence to the mold. Two geometries are used in the scope of this work: a simple cylindrical mold (Figure 1) and a generic casing of a 105 mm projectile (Figure 2).

Use of COMSOL Multiphysics
A fixed grid approach is chosen to model solidification through an enthalpy method based on the approach by Voller and Prakash [3]. This is implemented though the Heat Transfer with Phase Change interface. The melt is modeled as a single incompressible material under Laminar Flow interface and we ensure near-zero velocities in the solidified shell by using appropriate source terms in the momentum equation. After solidification, the shell cools down with the development of important thermal stresses. Conveniently, the Solid Mechanics interface is adopted, and in the absence of the visco-elasto-plastic data, the explosive is considered to be isotropic and thermoelastic with temperature dependent Young's modulus [1]. For gap formation, identity pair modeling is used at two levels: first, to account for adherence to the mold through a user-defined cohesive zone model (CZM), and secondly, to integrate thermal resistance due to the air gap formed.
Results
The model provides the temperature profiles expected during cooling and gives information about residual stresses and gap formation, which can be useful to predict a reliable performance of the solidified shell from possible crack locations. Those defects are usually linked to inadequate stress-temperature profiles during cooling. Moreover, a V&V procedure is adopted whereby the modeling approach has first been verified against a benchmark test problem - the Weiner and Boley solution [4] for a semi-infinite solidifying slab (Figure 3). Then, the simulation results for the projectile will be validated against those from an experimental setup.

Conclusion

The energetic materials and explosives sector is a constantly developing industry touching a wide range of activities that includes mining operations, law enforcement and military applications. Our research is focused in providing a technological edge as we target a comprehensive numerical model to study the influence of various process parameters on the quality of explosives charges. Most importantly, we aim to be among the first to report a model integrating adherence and investigate whether it influences shrinkage. As our industrial partner, General Dynamics-OTS Canada will use the fallouts of the research work to optimize their own production schemes.

Reference

References

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3. Voller, V.R. and C. Prakash, A fixed grid numerical modelling methodology for convection-diffusion mushy region phase-change problems. International Journal of Heat and Mass Transfer, 1987. 30(8): p. 1709-1719.
4. Weiner, J.H. and B.A. Boley, Elasto-plastic thermal stresses in a solidifying body. Journal of the Mechanics and Physics of Solids, 1963. 11: p. 145-154.

Figures used in the abstract

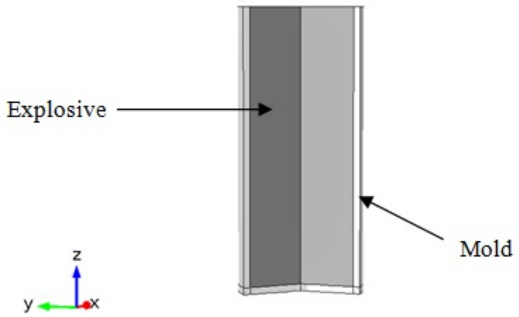

Figure 1: Cylinder

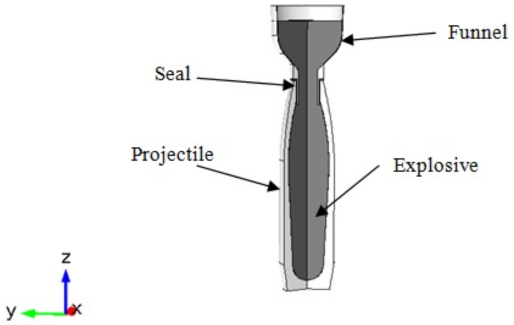

Figure 2: 105 mm projectile

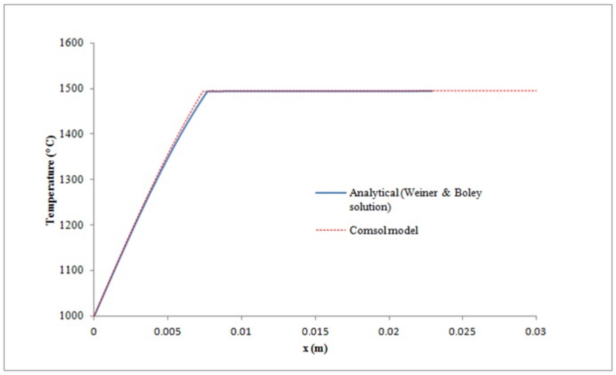

Figure 3: Verification procedure - Temperature profile at t = 5 s