Current Issues in the 
Numerical Simulation of Casting Processes

C. AGELET DE SARACIBAR † & M. CERVERA †
ETS Ingenieros de Caminos, Canales y Puertos
International Center for Numerical Methods in Engineering
Edificio C1, Campus Norte, UPC, Gran Capitán s/n, 08034 Barcelona, Spain

M. CHIUMENTI ‡
International Center for Numerical Methods in Engineering
Edificio C1, Campus Norte, UPC, Gran Capitán s/n, 08034 Barcelona, Spain

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† Professor of Continuum Mechanics, Phone 34-3-401-4517, Fax 34-3-401-7403, E-mail agelet@xanadu.upc.es
‡ Professor of Structural Mechanics, Phone 34-3-401-6992, Fax 34-3-401-6717, E-mail cervera@xanadu.upc.es
‡‡ Graduate Research Assistant, Phone 34-3-401-7403, Fax 34-3-401-6517, E-mail chiument@xanadu.upc.es
CURRENT ISSUES IN THE NUMERICAL SIMULATION OF CASTING PROCESSES

C. Agelet de Saracibar, M. Cervera & M. Chiumenti
ETS Ingenieros de Caminos, Canales y Puertos
International Center for Numerical Methods in Engineering
Edificio C1, Campus Norte, UPC, Gran Capitán s/n, 08034 Barcelona, Spain

Abstract - In this paper an up-to-date numerical model for the computational simulation of coupled thermoplastic frictional contact problems, focussing in casting processes, is presented. Fractional step methods, arising from isothermal and isentropic split of the governing equations, have been used to solve the nonlinear coupled system of equations.

INTRODUCTION: In spite of important progresses achieved lately in computational mechanics, the large scale numerical simulation of coupled thermomechanical contact problems continues to be nowadays a very complex task due mainly to the highly nonlinear nature of the problem. During the last decade, a growing interest on these and related topics, has been shown by many industrial companies, such as automotive and aeronautical, motivated by the need to get high quality final products and to reduce manufacturing costs. In this paper a coupled thermomechanical model suitable to simulate industrial casting processes is presented.

PROCEDURES, RESULTS AND DISCUSSION: The local system of partial differential equations governing the coupled thermomechanical initial boundary value problem is defined by the momentum and energy balance equations, restricted by the inequalities arising from the second law of the thermodynamics. This system must be supplemented by suitable constitutive equations. Additionally, one must supply suitable prescribed boundary and initial conditions, and consider the equilibrium equations at the contact interfaces. Micromechanically based phenomenological models of infinitesimal strain plasticity adopt a local additive decomposition of the strain tensor into elastic and plastic parts. Hardening mechanisms in the material are characterized by an additional set of phenomenological internal variables. An additive split of the local entropy into elastic and plastic parts is adopted, where the plastic entropy is viewed as an additional internal variable arising as a result of dislocation and lattice defect motion. This additive split of the local entropy was adopted by Armero & Simo [1993]. A J2-thermoplastic model is defined by a free energy function including a small strains hyperelastic response, a thermoelastic coupling, a thermal contribution, a hardening plastic potential and a latent heat contribution in the phase change front. Plastic response has been modeled by a J2 temperature dependent model, including hardening due to plastic deformation and thermal softening. A pressure and mean gas temperature dependent thermal contact model has been used. Additionally, a gap dependent thermal contact model has been used to take into account surface heat convection between the two bodies, when they separate from each other due to the shrinkage of the metal during solidification. Heat generation due to frictional dissipation has been also included. Frictional contact constraints have been modeled using a penalty method. See Agelet de Saracibar [1996] for a detailed formulation of coupled thermomechanical frictional contact problems. The mechanical behavior in the liquid, for an isothermal phase change, or in the liquid and mushy zone, for a non isothermal phase change, has been modeled by using a modified shear modulus defined in terms of the the phase change function representing the liquid fraction.

The use of an operator split, applied to the coupled system of nonlinear ordinary differential equations, and a product formula algorithm, leads to a staggered algorithm in which each one of the subproblems defined by the partition is solved sequentially, within the framework of classical fractional step methods. Contrary to common practice, the evolution equations for the microstructural internal variables are enforced in both phases of the operator split. A Backward-Euler (BE) time stepping algorithm has been used and two different operator splits, isothermal and isentropic, have been considered. In the isothermal split the coupled system of equations is partitioned into a mechanical phase at constant temperature, followed by a thermal phase at fixed configuration. Within the context of the product formula algorithm, note that using the entropy form of the energy equation, the elastic entropy computed at the end of the mechanical partition is used as initial condition for the solution of the thermal partition. In the alternative isentropic split, introduced by Armero & Simo [1992,1993], the coupled problem is partitioned into a mechanical phase at constant entropy, followed by a thermal phase at fixed configuration, leading to an unconditionally stable staggered
scheme. An efficient implementation of the split can be done using the temperature as primary variable. Isentropic conditions in the mechanical phase can be locally imposed by computing the local evolution of the temperature at constant elastic entropy. Here the additional design constraint of constant latent heat, during the mechanical phase, has been assumed.

**Numerical Simulation:** *Cylindrical aluminium solidification test.* This example, taken from Celentano *et al.* [1996], is concerned with the casting process of a cylindrical aluminium specimen in a steel mould. Assumed starting conditions in the numerical simulation of the casting process are given by a completely filled mould with aluminium in liquid state at uniform temperature. The initial temperatures of the aluminium and the mould were 670°C and 200°C, respectively. Only gravitational forces have been assumed. The material properties for the aluminium have been assumed to be temperature dependent, while constant material properties have been assumed for the steel mould. Geometrical and material data can be found in the above reference. A gap dependent convection-radiation coefficient between the aluminium and the steel mould has been assumed. Numerical simulation was done up to 90 secs. of the solidification test using a time increment of 1 sec.

Bottom left Fig. shows the temperature evolution at the casting center, casting surface and mould surface for an intermediate section. A typical temperature plateau due to the release of latent heat during solidification can be seen in the casting center point of this section up to 15 secs. approximately. Bottom right Fig. shows the evolution of the radial displacements at the casting and mould surfaces for the same intermediate section. Difference between the two curves gives the gap distance evolution at the choosen section. Temperature and air gap evolution predicted by the model compare very well with experimental and numerical results given in the above reference. A data sensitivity analysis has shown a strong influence of the heat convection coefficient between aluminium and mould in the temperature evolution.

**CONCLUSIONS:** A numerical model for the analysis of coupled thermomechanical problems, involving frictional contact and thermal multiphase change phenomena, has been presented. The model has been successfully applied to the numerical simulation of casting processes. Temperature and air gap evolution predicted by the numerical model compare very well with experimental and numerical results available.

**REFERENCES:**