Computer Simulation with CaPS of an Aluminum Plate Casting

by

H. M. Domanus and R. C. Schmitt
Argonne National Laboratory
Argonne, Illinois 60439

and

L. Chuzhoy and L. Nastac
Caterpillar, Inc.
Peoria, Illinois 61629


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ALUMINUM PLATE CASTING

H. M. Domanus and R. C. Schmitt*
Argonne National Laboratory
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L. Chuzhoy and L. Nastac
Caterpillar Incorporated
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Abstract

A simulation of a benchmark test casting has been performed with the CaPS-3D casting process simulator software. The test casting was made at the University of Birmingham in the UK for the 7th International Conference on the Modelling of Casting, Welding and Advanced Solidification Processes. The measured results were not available prior to the simulation, hence the simulation is a blind prediction.

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Introduction

Specifications for a benchmark test casting were provided in Ref. 1, and details of the basin and clarification of its position, along with suggested thermophysical properties, were provided in Ref. 2.

The test casting is a 10-mm-thick pure aluminum plate measuring 200 mm wide and 100 mm high. The mold cavity consists of a sprue, well, runner, gate, and bottom-filled plate. The 380-mm-high sprue is rectangular in cross section and is linearly tapered, having dimensions of 15 x 19.2 mm at the top (inlet) and 15 x 5 mm at the bottom.

Because modeling the entire basin would add significant computer time to the simulation, a truncated basin with a 55 x 50 x 25 mm volume above the sprue was modeled. This accounted for the 25 mm head above the sprue entrance and allowed for a decrease in flow area from the 55 x 50 mm basin inlet to the 15 x 19.2 mm sprue inlet. This area ratio reduces inlet momentum effects by one order of magnitude.

CaPS SOFTWARE

The Casting Process Simulator (CaPS) software performs detailed multidimensional, transient calculations of mold filling and subsequent solidification of gravity-fed sand castings. The first version, CaPS-2D [4], was developed during Phase I of the Casting Modeling Consortium under the sponsorship of U.S. industry and the U.S. Department of Energy (DOE). Since then, CaPS has been extended to three dimensions and has had several improvements. The simulation reported here used the CaPS-3D, Version 2.0, software package.

CaPS interfaces with a PATRAN neutral file to describe the geometry by volumes (hyperpatches) and surfaces (patches). The volumes are grouped into user-meaningful sets (named components) that are later used for meshing and initial condition assignment. The surfaces are also grouped into sets for later use in mesh considerations and boundary condition assignment.

CaPS uses a finite-volume formulation on a structured mesh. The software contains an automatic mesh generator that renders the geometry into a structured mesh. Visual graphical interfaces are used to generate and evaluate the mesh and to assign boundary and initial conditions to the named components in the geometry specification.

Conservation equations of mass, momentum, and energy are applied to each cell in the mesh. A volume-of-fluid (VOF) concept is used in the procedure to track the liquid/gas interface as the melt fills the mold. While the mold is filling, a semi-explicit solution scheme is used. After the mold cavity has filled, a fully implicit algorithm can be employed.
Geometry

The origin was chosen in the center of the back surface of the plate, with gravity in the negative z direction.

Six volumes were defined, corresponding to the plate, gate, runner, well, sprue, and basin. The collection of these six volumes defines the named component CAPSGEOMETRY, which is meshed. A named component, BASIN, was also defined. The surface at the top of the basin, where fluid is replenished, is named INLET. All mold-cavity surfaces were grouped into a named component called WALLS.

Boundary and Initial Conditions

Initially, the mold cavity was empty and the BASIN was full of 700°C liquid aluminum. A 1 atm pressure boundary condition and a 700°C temperature boundary condition were applied at the INLET for replenishing liquid entering the BASIN. The sand mold was accounted for by a thermal boundary condition that models the transient heat transfer into the sand. This condition was imposed on the WALLS. The sand mold was initially at a temperature of 20°C. A 1 atm back pressure was applied to the liquid/gas interface.

Material Properties

Suggested thermophysical properties were provided as part of the benchmark specification package [2]. Liquidus and solidus temperatures were given as 660.4 and 635°C, respectively. The suggested specific heat and the viscosity of pure aluminum differed significantly from standard values. Therefore, thermophysical properties were taken from the Metals Handbook [3].

Specific heat as a function of temperature was constructed by adding a triangular representation of latent heat between the liquidus and solidus specific heats. The suggested specific heat table indicated latent heat values that are approximately 30% lower than the handbook values.

For viscosity, the handbook value of 1.235E-3 Pa•s was used above the liquidus temperature. From the liquidus temperature to the midpoint between liquidus and solidus temperatures, a mildly increasing viscosity was used. From this midpoint to the solidus temperature, a rapidly increasing viscosity was used.

Results

A 14 x 51 x 87 partitioned structured mesh was used for the simulation. The 4680-cell mesh included the mold cavity and the model basin. Molten aluminum flowed from the basin into the sprue, and some aspiration was observed in the sprue. The small well filled rapidly and the aluminum flowed into the lower portion of the runner. A void region formed temporarily in the upper area of the runner between the sprue and the gate. As the runner filled, a recirculation region formed at the far end, with the fluid flowing along the bottom and returning toward the gate along the upper portion of the runner. As the fluid entered the gate, a
small plume formed, then subsequently collapsed, filling the runner and the bottom portion of the plate. Predicted filling time for the plate is 2.15 sec.

The filling patterns are shown in Figs. 1a-1i at the requested times[1].

Temperature histories at seven locations in the plate were requested. Locations are left-to-right, then top-to-bottom on the plate, where location 1 is at the top-left nearest the sprue.

Coordinates for the seven locations (in mm) are:

Location 1 = (5, -90, 40)  
Location 2 = (5, 0, 40)  
Location 3 = (5, 90, 40)  
Location 4 = (5, 0, 0)  
Location 5 = (5, -90, -40)  
Location 6 = (5, 0, -40)  
Location 7 = (5, 90, -40)

The seven cooling curves are shown in Figs. 2a-2g over the 240-sec transient simulation, as requested [1].

Summary

An aluminum plate casting was simulated with the CaPS-3D software. Setup of the problem included inputting the geometry, assigning the boundary and initial conditions, and meshing. This required ~1 person-hour. The automatic meshing took 4 cpu seconds on an HP 735. Approximately 2 person-hours was spent in constructing the property library files for the sand and aluminum, due to the corrections required for the suggested aluminum properties. The 240-sec simulation sued 199 cpu minutes on an HP 735. Postprocessing of the results took longer because we decided to investigate a different postprocessing package to analyze the CaPS simulation results, rather than using the PATRAN package with which CaPS is currently interfaced.

References
