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MODELING PERMANENT MOLD CASTING OF ALUMINUM

Dr. Daniel P. Cook
Department of Mechanical Engineering
University of Nevada, Las Vegas
Las Vegas, Nevada 89154
Email: dpcook@me.unlv.edu

Sachin S. Deshmukh
Department of Mechanical Engineering
University of Nevada, Las Vegas
Las Vegas, Nevada 89154

David P. Carey
Department of Mechanical Engineering
University of Nevada, Las Vegas
Las Vegas, Nevada 89154

ABSTRACT

Modeling the complex, coupled fluid flow, heat transfer and solidification phenomena taking place in metal casting is a challenging task. The quality of any metal casting depends on many parameters such as the type of mould, rate of filling, and rate of solidification. Optimization of these operational parameters is very important in reducing casting defects such as oxide inclusions and porosity. This paper addresses the first steps in validating a computational fluid dynamics (CFD) model of permanent mold casting of aluminum. A mathematical model of the casting system has been developed using the commercial CFD package StarCD. A physical model of the system has been used to validate the mold filling phenomena in the process. Comparison of the results from these models will be presented.

1 INTRODUCTION

The shape casting of liquid metals is one of the oldest metal fabrication techniques and is still widely used for the production of near net shape metal products. The quality of any final metal casting is dependent on a large number of parameters. These include operational parameters of the casting process itself, e.g. rate of mold filling, mold material, and rate of heat extraction, and physical parameters of the metal being cast, e.g. viscosity, density, and specific heat. Optimization of these parameters to obtain high quality finished product is considered by many to be as much an art as a science, and hands-on experience in the foundry is as valuable as theory.

The use of computational fluid dynamics (CFD) software to aid in the design and optimization of shape casting operations is well accepted in both the academic and industrial communities. Modern CFD applications not only calculate fluid flow and heat transfer, but also the mold filling, nucleation of the solid phase, and diffusion effects that govern the final microstructure of the casting. At issue when using these multi-physics modeling applications is how well they can be validated both numerical and phenomenologically. In the first case, one asks ”Is the code performing its calculations correctly?”, while in the second case, one asks ”Is the model of the physics correct?” Because of the complexity of the model, it can be quite difficult to validate results beyond the level of ”Well, it looks right”, which, in the end, requires some a priori knowledge of what the results are likely to be.

Experimental investigations of the mold filling and solidification in aluminum casting was performed extensively by researchers at the University of Birmingham (1), and the results from these experiments were the basis for the benchmark competition at the Modeling of Casting, Welding and Advanced Solidification Processes (MCWASP) VII conference in 1995 (2-10). Numerical models based on finite volume, finite difference and finite element discretization techniques were used to calculate the mold filling behavior in an aluminum, sand casting process. The results were then compared to experimental data collected using real-time, x-ray techniques. While some of the numerical codes performed in a satisfactory manner, many of them needed some post facto manipulation to obtain truly accurate results.

The investigation detailed in this paper is the first stage of a comprehensive effort to develop an integrated experimental and numerical casting facility. Numerical models of the filling phenomena in a permanent, gravity-fed mold were developed using

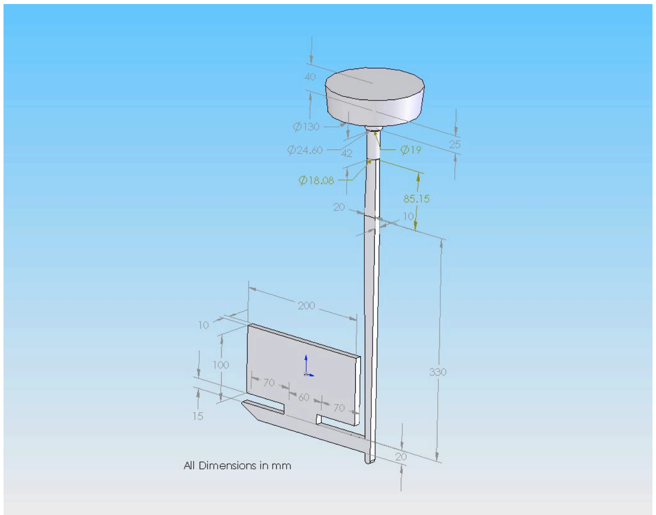

Figure 1. Diagram of experimental model showing dimensions.

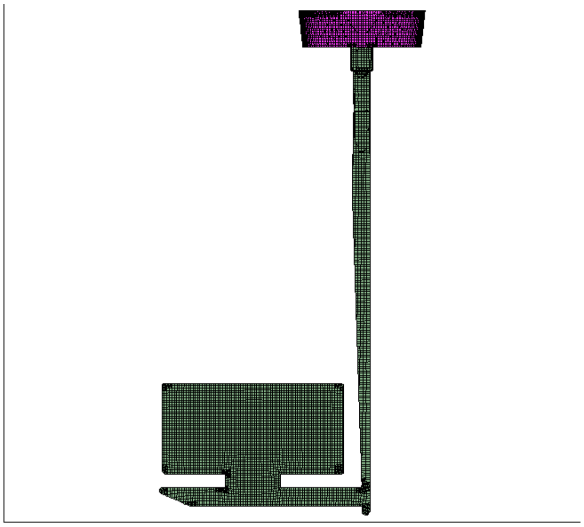

Figure 2. Mesh and solution domain of the computational model.

the commercial CFD package StarCD, a general purpose, finite volume based, CFD code developed by CD-Adapco. A transparent, physical model of the permanent mold was built to validate the filling algorithms used by StarCD. This paper will give details on the development of these experimental and numerical models and compare the results obtained from each.

2 EXPERIMENTAL MODEL

The experimental model was made from transparent acrylic so as to have a clear view of the free surface of water and air medium. Figure 1 shows a diagram of the experimental model with the mold cavity, gating channels and storage tanks with all the relevant dimensions. For these experiments, whole milk was used as the filling liquid because it was opaque to visible light. The filling of the mold was captured using a Basler A602f CCD camera. The camera was connected to an Apple Macbook Pro using a Firewire cable. Uncompressed digital video images were captured at a rate of 100 frames per second using the video capture software Shredcam. These video streams were then viewed with Quicktime and individual frames were saved to file for comparison with the numerical results.

3 NUMERICAL MODEL

StarCD is a general purpose CFD application which solves the coupled continuity, momentum, energy and species equations using the finite volume method. (15, 16). StarCD is capable of solving steady-state or transient problems, with compressible or incompressible fluids under laminar and turbulent flow regimes using standard 2-equation turbulence models and Large Eddy Simulation (LES) techniques. The velocity-pressure coupling is accomplished using algorithms such as SIMPLE and PISO. Free surface calculations are carried out using the Volume of Fluid (VOF) method. Figure 2 shows the mesh and solution domain used in the numerical modeling. The domain consists of three main parts: 1) the upper reservoir, 2) the downspout and runner, and 3) the mold cavity. Initially, all the liquid is contained in the reservoir. At time t = 0 seconds, the liquid is allowed to flow down into the down spout, runner and mold cavity. Wall boundary conditions were applied on the sides of the mold cavity and downspout. Two pressure boundaries were placed on the top of the mold cavity to allow for air to escape from the mold cavity. At these positions atmospheric pressure was specified. Finally, the top of the reservoir was also specified as a pressure boundary, with a value that accounted for the height of the liquid in the reservoir. The mesh consisted of 96472 cells with an average size of 2.5 millimeters.

The spatial discretization scheme used in the simulation was StarCD's proprietary "Monotone Advection and Reconstruction Scheme" (MARS). This is a second-order accurate differencing scheme that uses a multi-dimensional Total Variation Diminishing (TVD) algorithm that reconstructs the cell flow properties on the cell faces, these are then used to calculate the face fluxes for all the advected properties. The transient discretization was accomplished using a fully implicit algorithmThe velocity-pressure coupling was achieve using the "Pressure Implicit with Splitting Operators" (PISO) scheme.

The time step used in the calculations was 0.001 seconds. The problem was integrated for a total of 4 seconds. Calculations were conducted on an Itanium 2 cluster running GNU/Linux. Typically, calculations were conducted on 8 processors for a total runtime of approximately 15 hours.

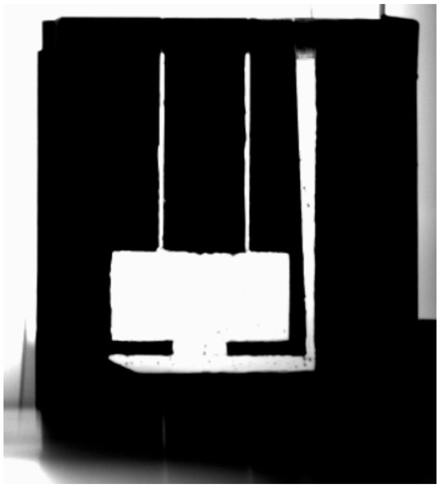

Figure 3. Experimental mold prior to filling.

Figure 4. Experimental mold 0.73 seconds after filling begins.

4 RESULTS

During experimentation, the mold filled in slightly less than 2 seconds. Figures 3,4 and 5 show video data that was captured prior to the commencement of filling, and at times of 0.73 seconds and 1.11 seconds respectively. The highly turbulent nature of the flow is readily apparent from these images.

Figure 6 and 7 show calculated results from StarCD at times of 1.0 and 1.5 seconds. Although not exact, the same trends in the shape of the free surface can be seen in figs. 4 and 6, and in 5 and 7. The disturbing trend is that the numerical model consistently overestimates the time necessary for the mold to fill. In all cases, the level of the calculated free surface in the mold cavity lags the actual position of the mold cavity by 20-25%.

Figure 5. Experimental mold 1.11 seconds after filling begins.

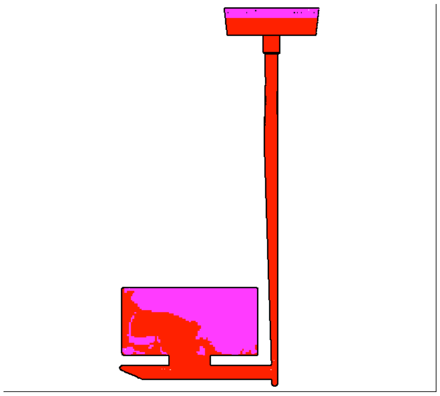

Figure 6. Computed results 1.0 second after filling begins.

5 CONCLUSIONS

Preliminary research into development of a simple mold filling experiment to use as a benchmark for computational models has been conducted. The results show that while the computational models may capture the trends of the free surface front, they overestimate the time necessary for the liquid-air interface to propagate through the mold cavity.

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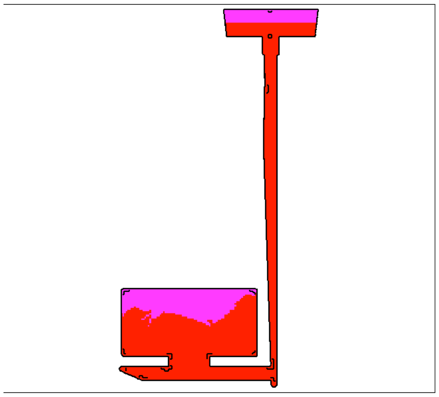

Figure 7. Computer results 1.5 seconds after filling begins.

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