Truchas: A Simulation Tool for Manufacturing

Advanced Simulation and Computing (ASC) Telluride Project Team

The Advanced Simulation and Computing (ASC) Telluride project is developing a highly parallel, coupled, continuum scale, multiphysics simulation tool called Truchas to aid nuclear weapon component manufacturing. A large team of researchers has contributed to the development of Truchas for more than a decade. Recent successes demonstrate that Truchas is making significant contributions to responsive and flexible manufacturing processes at Los Alamos National Laboratory and other National Nuclear Security Administration sites.

For example, the LANL Reliable Replacement Warhead (RRW) design relied heavily on casting technology and on modeling for a variety of components within pits, secondaries, and radiation cases. To meet the recent RRW hydro schedule, process modeling with the Truchas code was successfully utilized to develop casting parameters for the radiation midcase and resulted in an acceptable part 19 working days from receipt of the part definition. The short turnaround time hinged on the use of simulation tools including Truchas, and demonstrated a responsive capability for manufacturing that has never been seen in the nuclear weapons complex.

Examples of the types of Truchas simulations that were used to develop the casting processes for RRW are shown in the figures. The induction heating capability allows an engineer to evaluate the heating response of new mold designs. Figure 1 shows the temperatures developed in a hemispherical casting assembly after induction heating for 40 min.

The cooling rate and solidification time interval of the material in a casting are important indicators of casting quality. Figure 2 shows an example solidification time plot for a simple mold geometry.

Truchas is a unique tool because it incorporates all of the continuum physical models necessary to model metal casting processes.[1] Commercial products are also useful for process development, but none incorporate the breadth of models in the current release of Truchas. This set of features enabled the Telluride project to successfully complete a FY05 ASC Level 2 milestone to simulate casting of a plutonium pit from beginning to end. [1]

The following list shows the physical models required for such a simulation.

- Periodic behavior of electromagnetic waves and the resultant heat deposited in the components of the manufacturing system.
- Transfer of heat within system components and between the components and their environment by conduction, convection, and radiation (with view factors).
- Solidification, melting, and allotropic (crystalline) phase changes. These must incorporate the influence of alloy concentrations that can vary within the domain of the alloy (and may result in macro-segregation of alloy concentration).
- Flow of molten alloy. The flow algorithms must deal with dynamic interfaces and must permit evaluation of the redistribution of energy and alloy material due to fluid motion.
- The distortion and dislocation of system components (including mold and the metal product) due to stresses imposed both by temperature changes and by volumetric changes associated with phase change. This model must accommodate both elastic and plastic response to such stress.

Because of the complex geometry of real manufacturing systems, Truchas uses an unstructured computing grid. Truchas implements the numerical algorithms for these physical models as a sequence of separated solutions to the continuum partial differential equations that describe each phenomenon over a short period of time. The solution is advanced in time by a sequence of such steps.

Manufacturing processes are inevitably transient in nature because they aspire to change the form of materials over a period of time. Truchas is fully transient throughout its modeling and algorithms. It is also fully parallel in its operation, which permits the code to utilize the large computer clusters installed at LANL by ASC. Parallelism is achieved by subdividing the physical domain of the problem and assigning each section to a computing processor.

Each physics model employs a discretization method that is unique to the needs of the model. However, the resulting discretized equations are solved using a limited set of linear and nonlinear solvers. The combination of physical models and numerical algorithms makes Truchas a robust and efficient parallel program for simulating metal casting processes.

[1]The Telluride project is also working toward simulation of other manufacturing processes, including foam curing and welding.

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[1] D. Korzekwa, et al., "Truchas Simulation of Casting of the Qual Type 126 Pit (U)," Los Alamos National Laboratory report LA-CP-05-1224 (October 2005).

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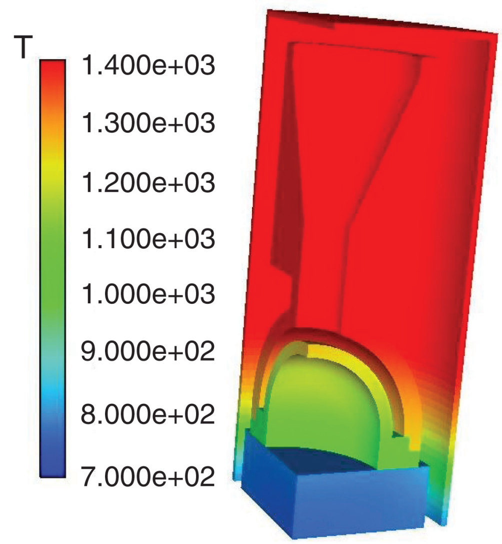

Fig. 1.
Temperature Distribution after 40 min of induction heating.

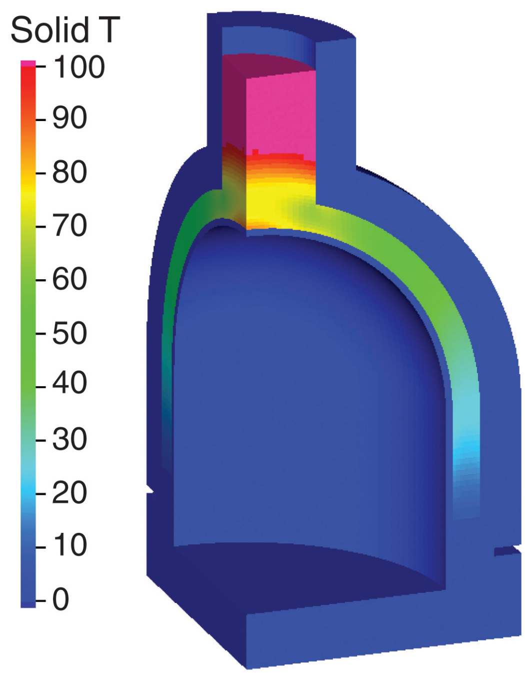

Fig. 2.
Solification time interval prediction.