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LLNL Casting Technology

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LLNL Casting Technology

Casting—the Dual Technology Key

Competition to produce cast parts of higher quality, lower rejection rate, and lower cost is a fundamental factor in the global economy. To gain an edge on foreign competitors, the US casting industry must cut manufacturing costs and reduce the time from design to market. Casting research and development (R&D) are the key to increasing US competitiveness in the casting arena.

Lawrence Livermore National Laboratory (LLNL) is the home of a wide range of R&D projects that push the boundaries of state-of-the art casting. LLNL casting expertise and technology include:

- casting modeling research and development, including numerical simulation of fluid flow, heat transfer, reaction/solidification kinetics, and part distortion with residual stresses.
- special facilities to cast toxic material
- extensive experience casting metals and nonmetals
- advanced measurement and instrumentation systems

Department of Energy (DOE) funding provides the leverage for LLNL to collaborate with industrial partners to share this advanced casting expertise and technology. At the same time, collaboration with industrial partners provides LLNL technologists with broader insights into casting industry issues, casting process data, and the collective experience of industry experts.

Casting R&D is also an excellent example of dual-use technology; it is the cornerstone for increasing US industrial competitiveness *and* minimizing waste nuclear material in weapon component production.

Annual funding for casting projects at LLNL is \$10M, which represents 1% of the total LLNL budget. Metal casting accounts for about 80% of the funding. Funding is nearly equally divided between development directed toward US industrial competitiveness and weapon component casting.

Casting Capabilities at LLNL

LLNL's outstanding achievement in casting technology is based on a unique blend of talented people solving challenging problems, powerful computing, and advanced facilities.

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Personnel

People are the most important ingredient in LLNL's casting R&D success. Multidisciplinary teams include experts in the following areas:

- software development and analysis—modeling physical phenomena and performing numerical simulations
- heat transfer, fluid mechanics, and thermal-structural modeling
- advanced measurement and instrumentation systems—with particular expertise in nuclear testing and laser inertial confinement
- material science and engineering—casting nuclear materials and understanding material behavior

State-of-the-Art Software

Software tools are increasingly important in reducing the trial-and-error associated with the development of cast parts. Analysis software has long been a significant strength of LLNL. For example, LLNL's DYNA, TOPAZ, NIKE, and CALE represent continually developing modeling tools incorporating state-of-the-art computational and numerical technology. New software developed inside LLNL is being combined with commercial software through collaboration (CRADAs) with commercial software developers.

Computers

As the detail of modeling casting process improves, the complexity of representing the physical phenomena increases. Computational speed, storage, and data display are important for complex physical models. LLNL uses the latest computers and computer technology including large parallel machines, a variety of CRAYs, and workstations. Our powerful workstations provide the environment for code development, model generation, and display, as well as computational capability for smaller, less complex problems. The CRAY supercomputers and new parallel computers are used for the computation of larger and more complex casting problems.

Facilities

Six LLNL casting facilities are available to the R&D teams. These facilities have the capability of casting a wide variety of pure metals and alloys, both radioactive and non radioactive.

We have a 75 kW induction tilt-pour casting furnace with a capacity of 25 kg. Melting can be done in an inert gas, air, or vacuum environment. Instrumentation ports and feed-throughs are designed into the system for measurements during the processing of material. The furnace is used to cast aluminum, copper, and iron alloys.

Our small vacuum induction furnace has a 15 kW high frequency power supply and can provide either high vacuum or inert gas environments. The furnace was designed for small melts or to conduct liquid metal experiments. A top plunger assembly can be used to bottom pour from a crucible into small casting molds.

We have designed and completed a new foundry facility for casting depleted uranium. This \$1M+ facility provides us with a capability to cast and to measure casting parameters for depleted uranium as well as other metals.

Our 37 kW electron beam furnace can be used to make specialty alloys which melt at high temperatures including refractory materials. Small ingots, 50 mm by 200 mm, have been produced using this furnace.

Casting of plutonium parts is carried out in our plutonium foundry. Our experience in this area is applicable to casting processes in other materials. An example of the mold and fill apparatus used in the facility is shown.

Description of Current Casting Research and Development Activities

Current LLNL casting technology development areas are:

Metal Casting

- Plutonium Die Casting
- Aluminum Sand Casting
- Casting Process Modeling
- Depleted Uranium Casting
- Aluminum Forming and Casting Modeling
- Cold Hearth Casting (semi-continuous casting) of an alloy whose components remain homogeneous for a relatively short time

Non-Metal Molding

- Reaction Injection Molding of Polymer/Glass Composites
- Resin Transfer Molding of Fiber Composite Panels

Plutonium Die Casting

William Bish, (510) 422-9165

The objective of this project is to develop die casting as a net shape process for fabricating plutonium parts. Plutonium represents a particular challenge because the molten metal is highly reactive with most metals. The motivation for this process is to greatly reduce the generation of nuclear waste and personnel radiation exposure associated with current manufacturing processes. We are collaborating with other national laboratories and production plants.

We are using pressurized inert gas to rapidly fill reusable precision metal molds with plutonium. The casting, done in a vacuum chamber, incorporates diagnostic instrumentation and a data acquisition system. Computational models are used to predict and analyze results, and enhance the die design. This technology may have application for die casting of other reactive metals.

The major deliverables for this project are:

1. A working prototype casting system for potential use in Complex 21.
2. Measurement techniques and modeling tools to predict appropriate operating parameters and die designs to successfully cast net shape parts.

Aluminum Sand Casting

Peter Raboin, (510) 422-1583

The objective of this collaboration is to identify and develop a new wear-resistant, castable, machinable, and low cost aluminum alloy to reduce the weight of automobile power trains. Sand casting of aluminum has not produced consistent quality parts; while for iron it has long been successful and inexpensive. This work will result in the development of sand casting technology for aluminum alloys which will produce low-cost castings of consistently good quality.

We will focus on modeling the sand casting process; concentrating particular attention on mold filling, solidification physics, and thermal-structural behavior of the part and mold. We will also characterize the material, and measure heat transfer, density, flow, and stress during the casting process. We are collaborating with two other national laboratories and a large automotive manufacturer on this project.

The major deliverables for this project are:

1. Validation of casting codes (NIKE, TOPAZ, and ProCast) for aluminum alloys.
2. Improved understanding of flow through patterns, gates, and filters.
3. Linkages of thermal, fluid, and mechanical codes for analysis.
4. Characterization of several aluminum alloys for use the codes.

Casting Process Modeling

Arthur Shapiro, (510) 422-5066

The age of high-precision industrial casting is upon us as we watch American companies, interested in cost savings, buy cast-metal parts from Europe and Japan in preference to American parts produced by traditional—and more expensive—forging methods. To stay competitive, we have been working on a computer code that can predict, with accuracy, the final shape and strength of cast-metal parts, as well as problems (e.g., porosity, deformation) we might encounter in the casting process. We are also conducting experiments to validate the code. By simulating the casting on a computer rather than constructing prototypes, we can cut costs and reduce the development cycle from design inception to introduction of the cast part into the marketplace. The emphasis here is on the production of components for the aerospace industry. The eventual end product will be a three-dimensional thermal-stress computer code that can predict the final shape, strength, and quality of cast aerospace components and help identify problems that might be encountered during manufacturing.

This is a Technology Transfer Initiative-funded project under a CRADA between LLNL, an aerospace casting manufacturer, and a commercial software company.

The major deliverables for this project are:

1. A material constitutive model that will transition between fluid and solid behavior.
2. A part-mold interface algorithm that models interface thermal contact resistance.
3. Validation of new software and modeling methods with experimental measurements.
4. A 3-D coupled thermal stress code by coupling the Lab's thermal code TOPAZ3D and stress code NIKE3D.

Depleted Uranium (Niobium Alloy) Casting

Allen Lingenfelter, (510) 422-6924

The objective of this DOD-funded project is to move from producing parts by wrought processing to near-net shape casting. The advantages include: reduction of waste from processing/machining, reduction of the number of processing steps, and improvement of the yield of acceptable parts.

We are using induction vacuum melting and reusable metal molds. Our two national laboratory collaborators are exploring the use of graphite and shell molds. We will use models to drive the experimental measurements of the casting process. This data will, in turn, be used to validate the models. The major challenges include achieving near-net shape while minimizing segregation.

The major deliverables for this project are:

1. Apply an existing (and/or developing) set of computational casting tools to model the casting process for this application.
2. Computationally predict the casting process using surrogate material.
3. Cast surrogate material and compare with predictions.
4. Computationally predict the Depleted Uranium-Niobium alloy casting process.
5. Cast the alloy and compare with predictions.

Aluminum Forming and Casting Modeling

Richard Couch, (510) 422-1655

The objective of this project is to provide a metal producer with software to simulate casting as well as metal forming processes. For casting, the software is being developed to model mold fill through solidification.

The software will be based on our arbitrary lagrangian-eulerian (ALE) techniques and is intended to run on single- as well as multiple-processor machines. The major technical issues being addressed are whether this approach can be made to be superior to existing simulation capabilities, and evaluation of the effectiveness of a robust implicit solution algorithm in saving compute time.

We are collaborating with a large metal producer and another national laboratory on this CRADA. Our expertise in developing algorithms to model the physics is being coupled with the manufacturer's processing experience and the other national laboratory's experience in parallelization and object-oriented numerics capability.

The major deliverables for this project are:

1. A general purpose metal forming software framework for multiple processor machines.
2. Specific algorithms to model the physics of the various physical model associated with metal forming and casting.

Cold Hearth Casting

Thomas Anklam, (510) 423-0417

The objective of this project is to eliminate at least 90% of the depleted uranium waste generated in nuclear weapon component manufacturing. Of the uranium entering the Y-12 complex, most becomes waste. Approximately half of this waste is a direct result of producing alloy and the remaining half from thermomechanical component fabrication.

We have developed a new approach to melting and refining uranium alloy using an electron beam cold hearth process in the presence of a hard vacuum. We are working in cooperation with two other national laboratories. We will reduce the current three melting steps to one, produce a purer product, and significantly reduce waste. Our unique facilities for melting uranium with an electron beam are part of an ongoing project.

The major deliverables for this project are:

1. Complete design, fabrication, and development of an electron beam melter and ingot caster (semi-continuous casting).
2. Produce an ingot from virgin uranium feed which meets metallurgical homogeneity and purity specifications.
3. Produce an ingot from Y-12 scrap material.
4. Complete initial experiments and develop computer models to characterize beam/pool interactions, thermal distributions, and flow fields in the hearth.
5. Document the results and outline a plan for process optimization and design of a production prototype unit.

Reaction Injection Molding of Polymer Glass Composites **Steve Deteresa, (510) 422-6466**

The objective here is to determine which production variables should be controlled to minimize residual stresses in structural reaction injection molding (SRIM). We will develop a model to simulate the physical process associated with residual stress production in SRIM parts.

The chemical curing process increases the temperature which accelerates curing. Since the nature of a composite is nonhomogeneous, the rate of cure varies throughout the part. As the resin cures, it shrinks and becomes increasingly viscous until solidification occurs. Differential curing and shrinkage contribute to forming residual stresses.

This is a combined experimental and modeling effort. We are collaborating with a large auto manufacturer able to share process and experimental data. We will add some additional features to previously developed LLNL software for modeling the process. Physical properties of the resin-catalyst and polymer-fiber will be experimentally measured. This data will then be used in the simulation models to evaluate the process parameters controlling residual stress.

The major deliverables for this project are:

1. Develop modifications of software tools for modeling the process.
2. Incorporate experimental data in the software.
3. A model of the SRIM cure process to predict how residual stress is controlled using the process parameters.

Resin Transfer Molding of Fiber Composite Panels **Roger Logan, (510) 423-4872**

Our objective in this CRADA is to create a modeling design tool that includes thermal, chemical, and rheological phenomenology involved in the Resin Transfer Molding (RTM) process. The RTM process replaces the expensive and labor intensive hand lay-up parts. Parts made in this manner will play an important role in aircraft and vehicle design. Our work will produce a tool for designing optimized molds and for predicting how to control process parameters to produce successful RTM parts.

We will model and perform experiments associated with the flow of resins through porous fiber preforms, capillarity effects, and effective permeability. The results will be used as a basis for the RTM process model. We are collaborating with a large automobile manufacturer on this project.

The major deliverables for this project are:

1. A modeling/design tool for the design of RTM process parts.
2. Experimental measurements of capillarity, permeability, and porosity.
3. A 3-D flow code for the RTM process.
4. Documented comparison of predicted versus measured mold performance.

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