

A person is shown from the side, working at a desk with two computer monitors. The left monitor displays a 3D CAD model of a mechanical part with a circular feature. The right monitor shows a software interface with various data fields and graphs. The person's hands are visible on the desk, near a keyboard and a pair of headphones. A large blue diagonal overlay covers the right side of the image, containing the title text.

Simulation- Driven Design for Investment Casting Optimization

Impro

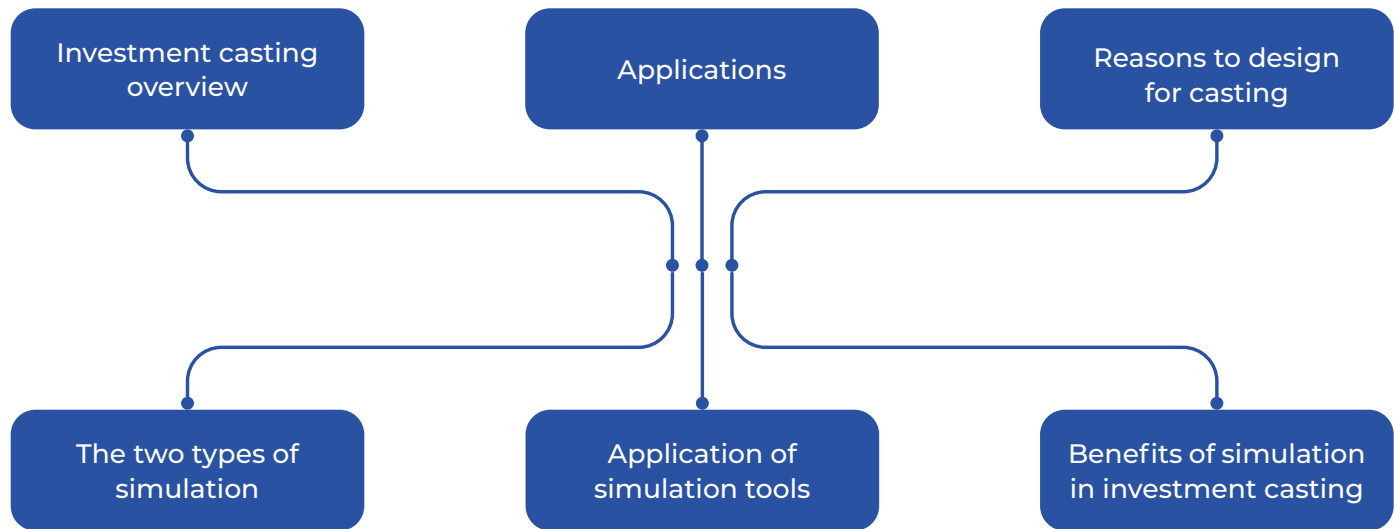
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The investment casting process is used to make intricate, often high-value, parts in a wide range of alloys. By designing parts for the process it's possible to reduce waste and compress the development lead time.

The challenge with this is the complexity of the process. Even with deep casting experience, liquid flows, heat transfer, and metal solidification are all very difficult to predict. Furthermore, as investment casting uses expendable molds, mold production and the casting process must both be optimized.

Modern simulation tools provide an answer. Using these, skilled foundry specialists can predict problems and explore solutions, before tooling is made or the part design finalized. This eBook explains how it's done, under the following headings:



Investment Casting Overview

Casting processes are used to make metal shapes by pouring molten metal into a cavity and letting it solidify. In the case of investment casting, that cavity is formed in a ceramic shell. The shell is made by coating a wax pattern with ceramic slurry. The pattern replicates the shape of the cavity needed, which comprises the part or parts being cast, plus the metal feeding system.

The wax pattern and associated feeding channels (sprue, runners, gates and risers), are produced by injection molding. Typically, each pattern is attached to runners, gates, and risers, and the runners are joined to the central sprue. The resulting “tree” then goes through a series of dipping and drying cycles to build up a shell strong enough to hold the mass of metal that will be poured in.

After the final drying step the wax is melted out to leave the mold cavity or cavities. Hot metal is poured in and allowed to solidify, after which the shell is broken apart to release the parts.



Applications

Investment casting delivers high accuracy and is particularly good at forming features like thin internal walls and precise bores. It also yields excellent surface finish and can reproduce fine detail.

This minimizes the amount of machining needed, and can permit part consolidation. It's often used with hard-to-machine and high value alloys like stainless steel, titanium, and superalloys.

Applications range from valve bodies and automotive components to parts used in industrial process equipment and medical implants. Parts used in gas turbine engines are often investment cast as a way of producing the intricate system of cooling channels and galleries needed.



Reasons to Design for Casting

Investment casting is often selected over other casting processes for its ability to produce complex geometries. However, as an expendable mold process – a new pattern and mold are needed for each part cast – design decisions made in the early steps determine both the efficiency of the process and the frequency with which defects will occur.

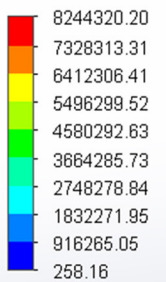
While part function is always the primary concern, designing for the investment casting process can reduce waste and cost. This requires considering every aspect of patternmaking and shell making as well as metal pouring and solidification. Doing so can eliminate defects caused by the way in which metal flows mold and solidifies in the mold. It can also optimize cooling and solidification rates, so achieving optimal grain structure within the part while driving down cooling time and increasing the production rate.

Historically, foundry experts used their process experience to optimize part design for the process. Based on what they had seen and learned previously, they would advise on features to avoid and where to make modifications as well as how to design the metal feeding system, all to reduce defects and increase efficiency. Today, while experience remains as important as ever, these experts are able to simulate fluid flows and heat transfer, and so gain an even deeper understanding of the process.

The Two Types of Simulation

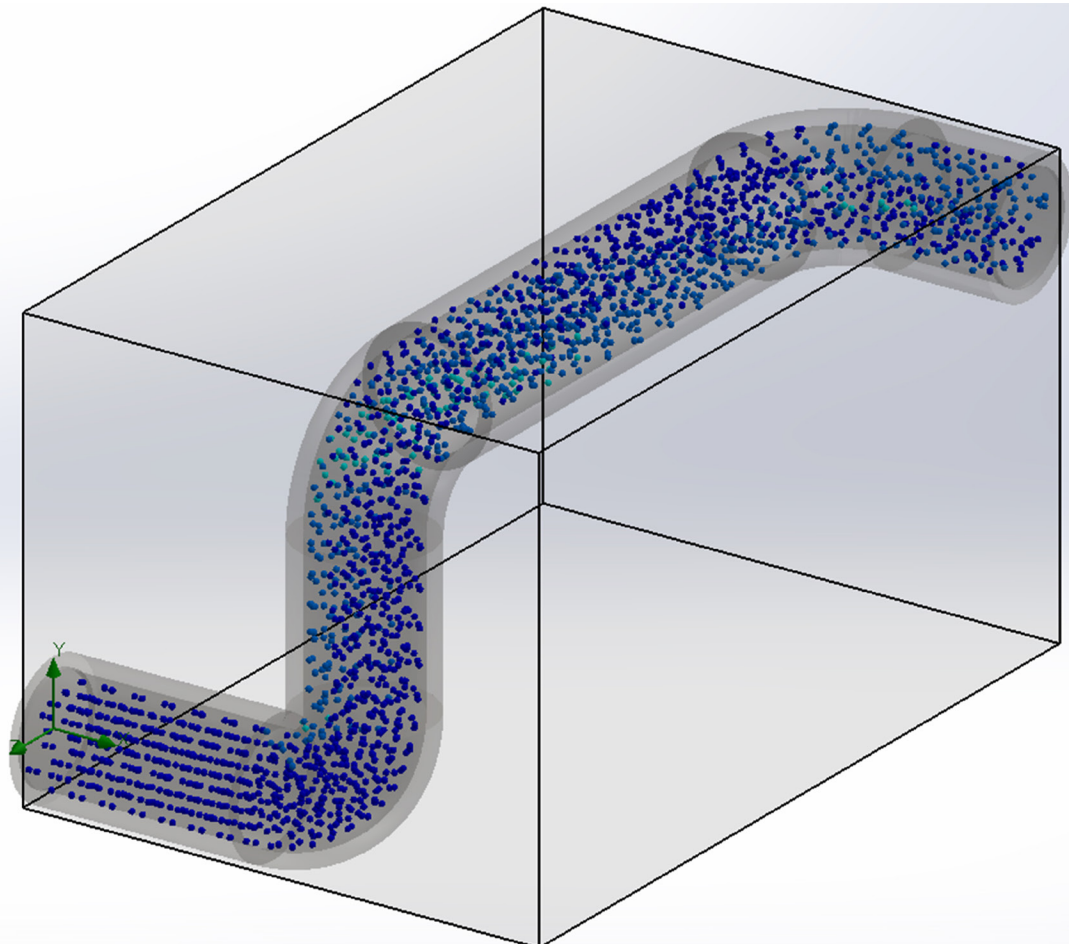
Fluid dynamics provides equations for predicting how liquids and gases will move under various conditions. In the heat transfer realm there are equations that predict radiation, conduction and convection effects. However, it's practically impossible to apply these to complex shapes like those encountered in casting, without using finite element methods.

The finite element approach is to decompose a shape into a mesh of small elements, each connected at the vertices or nodes. Fluid and heat equations are applied to each element and the results transferred to adjoining elements through the nodes. Performing this kind of analysis requires powerful software running on high-powered computers. A smaller mesh with more elements creates a higher resolution, and therefore more accurate, model.



Vorticity [1/s]

Flow Trajectories 1



Simulating investment casting requires software that performs both computational fluid dynamics and computational heat transfer analyses. Some of the biggest challenges in this are:

The viscosity of most alloys varies with temperature.

Heat loss from the shell (as the metal cools) is complicated by the influence of adjacent regions of the shell: heat from one region may be radiated onto another region, reducing heat flow.

Shell thickness must be known all around the mold cavity, as this too influences the rate of heat loss.

Application of Simulation Tools

Two prerequisites need to be met to achieve the goal of modeling how metal will fill and solidify within the mold cavity. First, there must be an accurate model of the cavity itself, plus the feeding system. Second, the model must account for varying thicknesses of ceramic shell around the cavity, as this determines local cooling rates.



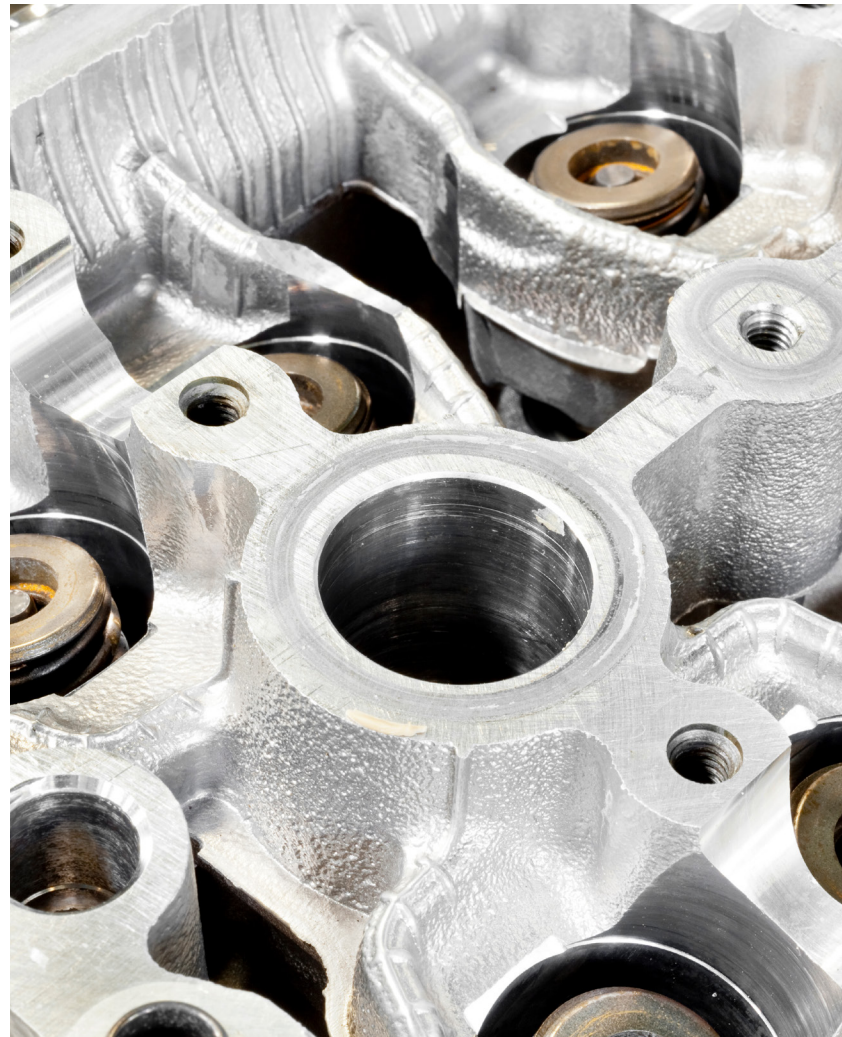
If pattern tooling already exists and parts have been molded, the dimensions of these can be used to build the cavity model. However, as simulation is usually performed before expensive tools are made, an alternative is to take cavity and feeder geometry directly from the CAD model. (Allowances, such as for shrinkage, will be applied as appropriate.) The limitation of this is that it assumes that the as-molded wax pattern and feeding system will be exactly as in the CAD.

A better approach is to model pattern and feeder system molding and use the output of that to build a virtual “tree”. This is then put through a simulation of the dipping process that predicts ceramic thickness all around the shell. This new geometric model then becomes the input to the process of modeling mold filling and metal solidification.

Benefits of Simulation in Investment Casting

As the discussion above shows, building an accurate model of how a particular part will be investment cast takes a lot of time and work. It is however much faster than making pattern mold tools, molding the pattern, building a shell and casting parts, only to discover that changes are needed.

Once an accurate process simulation is available its primary role is to enable experimentation. Foundry experts can use it to explore the effects of changes to aspects of both part and tooling design.



It's even feasible to conduct a formal design of Experiments (DoE) study to identify the best ways of optimizing the process.

Thus the main benefits of simulation are:

- **Faster development:** Fewer changes are needed to physical tooling, compressing the time needed to get parts to the customer.
- **Higher yields:** By optimizing part design to avoid defects like shrinkage and porosity, fewer parts will be scrapped during production.
- **Greater efficiency:** Higher yields result in better metal and foundry utilization, but in addition, simulation enables optimization of shellbuilding, pouring temperature, and solidification times, which can also boost efficiency and lower costs.

Merging Technology With Expertise

Manufacturers like investment casting because it produces high-quality, high-precision metal parts that need little-to-no machining. The downside is that it's a complicated process that takes time to fully optimize for a specific part geometry.

Fortunately, with modern simulation tools, it's now possible to model the entire process, effectively performing virtual investment casting. This enables identification of part design changes that will increase yields and reduce waste, and compresses the time needed to fully optimize the process.

As a leader in investment casting, Impro combines the latest casting tools and technologies with the skills and talents of our highly experienced foundry specialists to give customers exactly the parts they need. [Contact us](#) to discuss any applications or projects.





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