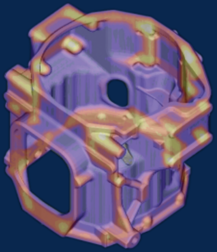
Casting Simulation

FAQ

AND ANSWERS



E-Foundry Lab, IIT Bombay

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Compiled and edited by

B. Ravi

E-Foundry Lab, IIT Bombay

Preface

You have attended casting simulation seminars, checked out software websites, witnessed live demos, even participated in hands-on sessions or simulation projects. Yet many doubts prevail. Are these software programs really user-friendly? What are the critical inputs? How accurate are the results? Here is a compilation of the most frequently asked questions about casting simulation, and their answers by experts. Have some more questions? Post them in 'The Hub' at E-Foundry website.

IIT Bombay, 2014

B. Ravi

Which casting metals, processes and phenomenon can be simulated?

In theory, any metal that can be melted and poured into a mould can be simulated.
In practice, simulation is limited to only those metals and processes for which relevant data is available. This includes thermo-physical properties of metal (like specific heat and viscosity at various temperatures) and process characteristics (like mould density and interfacial heat transfer coefficients). Widely used cast metals (like iron, steel, aluminium, copper, magnesium and zinc alloys) and major casting processes (green sand, investment shell, gravity die, and pressure die) can be handled by most simulation programs available today.

Which physical phenomena related to metal casting can be simulated?

There are three major phenomena. The first is molten metal flowing into the mould, accompanied by falling, splashing, streams separating, rejoining, and onset of freezing. The second is metal solidification, which is accompanied by changes in volume and formation of microstructure. The third is metal cooling to room temperature, which is accompanied by stresses and distortion. Solidification simulation is a mature technology. Coupled simulation of two or more events is complex, requires more computation time and is usually less accurate.

Which casting processes and phenomena can be simulated more accurately?

Gravity casting processes, in which casting solidification time is much longer than mold filling time, can be accurately modelled and simulated since only physical phenomenon (metal solidification) has to be handled.
An example would be heavy steel castings produced in sand molds. On the other hand, pressure die casting is much more difficult to simulate accurately, since it involves simultaneous multi-physics phenomena of metal droplet spray at high velocity instantaneously solidifying against the metal die walls.

What are the most important results from casting simulation?

Flow simulation gives the location, velocity and pressure of molten metal front during mould filling. Solidification simulation gives the temperature and cooling rate in all locations inside the casting and mould. Further simulation can provide phase distribution, microstructure, cooling stresses and casting distortion. All these results are displayed as colour-coded plots at different instants of time and can be played like a video animation. The results can usually be viewed in 3D as well as 2D cross-sections.

Which casting defects can be predicted by computer simulation?

Solidification-related defects: shrinkage cavity and porosity, can be accurately predicted by most simulation software. This is followed by flow-related defects: cold shut, misrun and sand inclusion. Blow hole and gas porosity are difficult to predict since they depend on a lot more shop-floor conditions which cannot be captured in simulation. Cooling-related defects: hot-tear, distortion and hard-spots can be predicted by a few simulation software, though with a lower level of accuracy.

Can we improve the quality and yield of a casting by simulation?

Simulation by itself does not improve casting quality and yield of a casting, but enables a casting engineer to virtually try-out different combinations of methods design and process parameters to identify the one that gives the desired quality with good yield. The improvements in quality and yield, and the time taken to achieve them, depend on the casting experience of the engineer for interpreting the simulation results, methoding knowledge for improving the casting design, and understanding of process capabilities for implementing the same on the shop-floor.

What are the major (essential) inputs required from the user?

Essential inputs for simulation include the 3D CAD model of the casting along with gating and feeders; mould and its elements including cavities, cores, vents, and feedaids (sleeves, covers, chills, coatings, etc.); specification of the corresponding materials, and critical process parameters (like pouring temperature and rate).
The casting model should include all allowances: shrinkage, draft, fillets, machining, and distortion. Any difference between the simulated model and shop-floor casting will lead to a mismatch between the virtual and real results.

Which default inputs are assumed by the system, but user can provide own values?

There are many parameters that are required for simulation and affect the accuracy of results, but are difficult to input by the users, and hence default values are assumed by simulation programs. These include various interfacial heat transfer coefficients (between metal-mould, mould-air, metal-air, metal-chill, chill-mould, etc.), limiting values for stoppage of metal flow and feeding, various choices of assumptions and approximations for optimizing computation speed and accuracy. Since most of these are neither easily understood nor available with the users, their values are taken from databases included with simulation software.

What is IHTC (interfacial heat transfer coefficient)?

The IHTC represents the rate of heat transfer per unit area per unit time, between a given pair of materials. It usually accounts for all modes of heat transfer: conduction, convection and radiation. The most important IHTC is between solidifying metal and surrounding mold. It is not constant; it is high in the beginning, when the temperature difference is large and the casting-mold pair are in perfect contact. The IHTC gradually reduces as the casting temperature falls, mold temperature rises, and air gap between them grows. The air gap itself is not uniform and depends on casting shape.

How can we get the correct value of IHTC (interfacial heat transfer coefficient)?

Simulation software usually provide the default values of IHTC between important pairs of materials: casting to mold, casting to chill, mold to air, etc. The IHTC database contains the values for different combinations of materials (ductile iron casting to green sand mold, etc.). If the values are not available for a particular combination, then either experiments need to be conducted by the user, and the data provided to the software to generate and incorporate the values in its database.

We only have 2D CAD drawings of castings. Is it possible to simulate?

Simulation requires a 3D CAD model of the casting, that too, a solid model (and not a surface model) implying that all mass properties can be computed. Any 2D drawings need to be manually converted into solid models using a 3D CAD software. Simple parts can be modeled within a few minutes to an hour. Very complex parts like gear boxes and engine blocks can take several days to model, that too, by expert CAD engineers. Once a 3D CAD model is prepared, it is easy to store, view, modify and exchange, and to evaluate using different types of simulation for function, stress and manufacturing.

How can we get 3D CAD models of castings for simulation?

There are three ways: (i) request the model from the OEM customer or tool maker, (ii) approach an engineering service provider, or (iii) create the model in-house using a suitable CAD software program. The level of difficulty increases from the first to the last, but this is compensated by better control on the output and other uses like design of methods and tooling elements, inspection planning and CNC machining.

Can we use a 3D scanner to create the CAD model of an existing casting?

Several types of contact and non-contact scanners are available today to create a cloud of points corresponding to the visible surface of the casting. These points are then connected to create the surface and eventually a solid CAD model of the casting. Internal features, especially narrow and curved holes cannot be scanned.
Non-contact scanners using white light or laser are very fast (take only minutes) and fairly accurate (less than 0.5 mm error).

What is the required format of 3D CAD model file for casting simulation?

Most simulation programs support the .STL (the neutral file format developed for rapid prototyping systems) owing to its simplicity and robustness. An .STL file essentially comprises (x, y, z) coordinates of the vertices of triangles completely covering the 3D model, and the outward pointing normal to those triangles. The OEMs are comfortable sharing .STL files of their part models since these files cannot be tampered. Increasing number of simulation programs also support other neutral file formats such as .IGES and .STEP.

What are the essential modules of casting simulation software?

There are three major modules of casting simulation software. The Pre-processor takes various inputs from the user, and sub-divides the entire mould along with casting, into a mesh of small elements. The Solver computes the temperature, velocity and other results at each element as a function of time. The Post-processor displays the results as colour-coded plots for visualization. Some casting programs have modules based on the type of mold or process (ex. sand, die, or investment casting). These contain process-specific variations of mathematical models and material databases.

What is the difference between FDM and FEM-based casting programs?

FDM stands for Finite Difference Method, in which the computation domain (casting and mould) is subdivided into structured (brick) elements. In Finite Element Method or FEM, the subdivision uses unstructured elements (like tetrahedrons). The latter can better approximate the casting and mould geometry with fewer elements, and thereby can give more accurate results, but the mesh generation is usually more cumbersome and error-prone. Most casting software programs therefore prefer FDM and its variations like Finite Volume Method (FVM) and Control Volume Method (CVM).

Can we use a general-purpose FEM program for casting simulation?

A general-purpose FEM program can be used for casting simulation, after incorporating the relevant mathematical models for metal flow, casting solidification and further cooling to room temperature. The necessary databases of temperature-dependent material properties (like density, specific heat and thermal conductivity) and process-dependent parameters (like interfacial heat transfer coefficients) need to be created. The program will need to be verified and validated. All this requires a high level of research expertise, time and effort, but gives the benefit of an excellent understanding of casting process modeling and computer simulation.

What is Vector Method? In what way is it different from FDM or FEM?

The Vector Element Method (VEM) is a revolutionary technique to locate hot spots inside a casting by computing the resultant of geometric modulus vectors (representing thermal flux) in all directions around a starting point. It does not require 3D mesh, and does not depend on interfacial heat transfer coefficients. Hence VEM is both fast and accurate in hot spot location, useful for quick design and verification of feeder designs. An improved Gradient Vector Method (GVM) uses a structured mesh, accounts for the properties of cast metal, mold materials, and feedaids (like chills and insulation), and provides more results including temperature.

How many casting simulation software programs are available today?

There are more than a dozen commercial casting simulation programs available today, developed by vendors from different countries in Asia, Europe and USA. Given the complexity and long development time, it is no surprise that all casting simulation programs have originated in leading universities and Government research labs worldwide, during the 1980s and 1990s, and refined by the respective development teams over the last 20 years. Most of the recent improvements have been in the front-end or graphical interface, to make them more user-friendly.

What are the evaluation criteria for purchasing casting simulation software?

There are three major criteria to evaluate the suitability of a simulation software for a particular organization. The first is functionality, which means that the software specifications should meet the desired requirements. The second is usability, which implies that the organization can indeed get the desired results with the available human resources. The third is cost effectiveness, which is measured by the tangible and intangible benefits against the investments (fixed and variable costs).

How can we evaluate the functionality of casting simulation software?

The software functionality can be initially checked by going through its brochure and technical specifications, industrial case studies, and feedback of similar customers. Then a benchmarking exercise should be carried out for a defect-prone casting produced in the foundry. Only the casting model and methoding layouts should be provided; not the defect location for each layout. Such a blind test will conclusively prove the accuracy of the simulation software in predicting the casting quality.

Are casting simulation programs user-friendly? How do we know?

Most software programs claim to be user-friendly, but this can be far from true, especially for foundry engineers who have little or no previous experience in CAD and FEM. The best way to ascertain the usability is to organize a live demonstration, preferably for one of the problem castings produced by the foundry. This can give a clear indication of the types of inputs, decisions, technical knowledge, and time involved. The quality of initial training and continued technical support also greatly contribute to the software usability.

What are the costs involved in establishing a casting simulation facility?

Initial costs include benchmarking exercise and evaluation, software license (annual or permanent option), computer hardware, and site preparation (room, furniture, AC). The cost of training and technical support for one year is usually included in the initial cost. Major recurring costs include salary of the simulation engineer, and maintenance of software and hardware. Software maintenance costs usually include minor upgrades, besides technical support over e-mail and phone.

What are the economic benefits from a casting simulation facility?

The most tangible (measurable) benefit is energy saving due to improvement in yield and quality, and increased capacity without adding more equipment. New casting development time is usually compressed to one third (from several weeks to just days), which is important for jobbing foundries. Production foundries can halve their total rejections (say, from 8% to 4% overall). Other (intangible) benefits include higher customer satisfaction (fewer complaints) and better employee morale (better output and longer retention).

Why are casting simulation software very expensive compared to CAD?

Most CAD software programs are based on standard geometric engines or kernels, and mainly differ only in terms of their user interface. Further, the user base of CAD is several millions, and technical support is relatively easy since there are a large number of CAD books, trainers, and other resources. In contrast, casting simulation software is highly complex, the user base is tiny, and technical support is challenging. As the awareness and number of casting simulation users grow, their cost is bound to come down.

What is the typical ROI for casting simulation software?

The return on investment for casting simulation software depends on the initial cost, usage (number of casting projects per year), order weight of simulated castings, and reduction in wastage of production resources. For typical casting simulation software implemented in a medium size jobbing or production foundry (annual capacity 5,000-10,000 tons), the initial investment can be usually recovered within a few months. It is often possible to recover the software cost with a single project involving an important large order.

Should we opt for in-house simulation facility or outsource to consultants?

In-house simulation facility is usually preferred by medium and large foundries, who continuously need to develop new castings, or improve the quality and yield of many existing castings in regular production. Foundries handling confidential components for aerospace, defense and other sectors also need to have in-house simulation facilities. They should have adequate qualified human resources to design, simulate and optimize the castings. Small foundries who do not meet the above criteria can opt for simulation services offered by consultants.

What are the recommended specs of computer hardware for simulation?

The hardware ranges from laptop and desktop computers to powerful workstations and computer clusters. The latter are needed for simulating coupled physics for complex and multi-cavity castings. For most castings however, desktop computers with Intel i5/i7 or equivalent CPU, 8-12 GB RAM, graphics card, and 100-200 GB of free hard disk space are sufficient for completing the simulation at reasonable accuracy within a few hours. Most simulation programs today work in both 32-bit and 64-bit Windows operating systems common in personal computers.

What is the role and importance of technical support for casting simulation?

The technical support team is usually responsible for initial benchmarking (before software purchase), installation and training (immediately after purchase). They also handle troubleshooting in the event of software not working for any reason, and re-training if any major upgrades are installed. Since casting simulation software are technically complex, the quality and speed of technical support are critical for successful continued usage and resultant benefits.

Is web or video conferencing suitable for software training and technical support?

Video conferencing enables multiple training sessions over a period, which are more effective than a single long session. It is also very useful for technical clarifications or troubleshooting advice at a short notice. There are many free or low-cost options for web-based video conferencing, if broad-band Internet is available (at least 1 Mbps). These allow video, audio, text-chat, and computer screen sharing, with option for switching the mouse control between the two sides. If internet speed is limited, then only screen sharing option can be used along with a telephone line for talking.

Why OEMs increasingly insist on a simulation report along with RFQ?

With Just in Time manufacturing philosophy adopted by most of the original equipment manufacturers, the cost of poor quality is much higher today. Further, new product development times have also reduced. Hence OEMs need to be assured that a foundry is capable of quickly developing a new casting, getting its quality 'right first time', and also keep the quality consistent ('right every time'). A simulation report is the best way to ascertain the capability of the foundry, and is therefore expected along with Request For Quote for new projects.

In what other ways simulation is useful to OEMs?

Original equipment manufacturers use the simulation results in many ways to improve overall quality assurance. Simulation shows difficult-to-feed areas (isolated hot spots), which can be either reduced in magnitude, or provided a feed path and feeder boss to ensure directional solidification. Such part design changes, can reduce the difference in weight between the designed part and as-cast part, which is often a contention between OEM and casting supplier. The simulation results can also be used to identify critical areas that need inspection, and provide useful insights for collaborative solutions through technical discussions.

Do we need knowledge of CAD and FEA to run casting simulation programs?

Older generation simulation programs, especially those built by customizing a Finite Element Method code, require a large number of input parameters to be specified by the users, and this requires a good knowledge of FEM as well as the underlying physics. New generation programs developed with the latest programming techniques, usually employ better assumptions and superior user interfaces, making them more intelligent and intuitive. This reduces the learning curve, number of user inputs, and time taken.

Is prior methoding experience needed to use simulation software?

For merely running a simulation program, prior experience in methoding of castings is not needed. However, such experience is very useful for correctly interpreting the results of simulation, matching them with shop-floor observations, and for improving the methods design before the next iteration of simulation. Since it takes several years to gain useful methoding experience, it is advisable to team up a senior methoding engineer with a CAD engineer, for effective utilization of simulation software.

How much time does it take to learn and start using simulation software?

The user interface for various functions, including inputs and results, can be learnt within one or two days and practiced over a week. However, understanding the importance of various parameters, learning how to interpret different results, and customizing of software database can take several weeks to months. This usually requires comparing the results of different projects, reading technical literature, and discussion with experts.

Can simulation software create gating and feeder models?

Most simulation programs expect the users to create the mould cavity layout with gating and feeders in a separate 3D CAD program, and import the entire casting for simulation. Based on the results, the users have to go back to the CAD program, make suitable changes, and re-import the model for simulation. Some simulation programs include basic solid modeling facilities to reduce the above hassle. Very few programs provide integrated design, 3D modeling, simulation and optimization of methods design.

Can simulation software optimize the gating and feeder designs?

Optimization implies achieving the desired quality along with high yield by iterations of simulation, interpretation of results, and modification of methods design. All of these tasks require human intervention. Some software programs provide initial design and models of gating and feeding, which helps in minimize the number of iterations. A few others run multiple simulations driven by user-defined criteria and range of design parameters, but this can take several hours for complete results.

Can simulation programs handle a new alloy composition provided by user?

Users can select an existing alloy or create a new entry in the material database of the software, and edit its composition. However, the thermo-physical properties of the casting alloy are required for simulation, and these values too need to be entered. It is not easy to generate the property values, since they require expensive experimental facilities and experienced technicians. Some software programs estimate the property values based on composition, but these are approximations, and need to be verified.

Do simulation results always match shop-floor observations?

Computer simulations are based on mathematical models that are approximations of the real-life. Metal casting process is highly complex with a large number of parameters and therefore impossible to simulate accurately. Still, the results of solidification simulation, such as shrinkage porosity location are fairly accurate. Indeed, if the results do not match, one should check if there are any discrepancies in what is simulated and what is produced (for example, size of gate or feeder neck).

Can computer simulation replace methoding engineers and foundry trials?

The casting simulation programs have come a long way, and are very useful for quickly exploring different methoding options for quality and yield improvement without expensive and cumbersome shop-floor trials. But simulation programs cannot replace experienced engineers, who can leverage their past knowledge to find the best solution in difficult cases. The results of simulation combined with the analysis of experienced engineers provide valuable insight, which is useful to analyse past mistakes (hindsight), and confidently develop new castings with minimal shop-floor trials (foresight).

Casting Simulation FAQ and Answers

can be accessed at

E-Foundry

**Online learning resources in
Casting Design and Simulation
for students, teachers, and
industry professionals**

National Knowledge Network Initiative