

Techniques for Ensuring Simulation Success: Software Setup, Calibration and Training

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Abstract

Many people are hesitant to begin using casting simulation software, fearing that the time and effort to learn the software will be too great, and that simulation results will not reflect actual shop floor experience. After implementing simulation software systems for almost 20 years, we have developed a series of guidelines for getting the most from your software investment through accurate and timely simulation results.

The three main areas of concentration are Software Setup, Calibration and Training. Software Setup refers to using the appropriate features of the simulation software to accurately represent your casting process. Calibration refers to using realistic property data for casting alloys, mold materials and coatings or other mold inserts. This may involve acquiring new data, or fine tuning existing data by comparing simulation results with shop floor experience. Training refers not only to pressing the proper buttons, but also to a good basic understanding of the processes that are being simulated. Good training also implies using the most efficient techniques, so that results are produced as quickly as possible.

This paper will give examples for each of these three areas, and will provide advice on how to prepare the most realistic simulations for Sand, Investment and Gravity Die processes. Specific examples are taken from SOLIDCast™, simulation software developed by Finite Solutions Inc.

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Introduction

Casting simulation software has now been available commercially for almost 20 years, yet many, many companies are hesitant to make use of it, in spite of the countless presentations and demonstrations of success. Why is this? Cost, of course, can be a big barrier, but several packages are very cost-effective nowadays, especially when compared with the cost and energy savings they can bring about. Even companies with 10 or fewer employees can cost justify such an investment.

For many, the biggest hurdle is fear of the unknown. Although you may have seen impressive results from simulations performed by others, the real question is, "Will I be able to handle this the way the expert does?". Another is, "Will my results actually show me what will happen in my shop?"

With over 750 software installations over those 20 years, we have found that the answer to both of the questions above, for the vast majority of foundries, is a resounding "YES!!" That does not, however, mean that implementation of casting simulation is a trivial matter. You need to have a plan, have resources, and a staff commitment in order for the project to move forward. There are three main areas to pay special attention to, which will lead to an effective use of simulation software. Those three areas are Software Setup, Calibration of Data and Training.

The balance of this paper is devoted to outlining the techniques that we have found will give you the greatest chance for success in your undertaking of computerized casting simulation.

Software Setup

Setting up and configuring a software package to properly simulate your specific process is probably the most important step in preparing for simulation success. While the main calculations are similar for all casting processes, there are significant variations in simulation details, and how the calculations are set up. By paying attention to those details, you can not only expect accurate simulation results, but also achieve those results in the shortest possible time. The major adjustments are listed below for each process. They are listed in order of simplest process to model to most complex process. The processes detailed are Sand Casting, Investment Casting and Gravity Die Casting.

Sand Casting

- Turn off Internal Heat Transfer Coefficients – Thermal properties determine how heat flows THROUGH a material, while Heat Transfer Coefficients(HTCs) determine what happens at the INTERFACE between materials. In sand casting processes, the insulating properties of the molding sand mask the effects of what is happening at the casting-mold interface. By ignoring these small effects, simulations can be speeded up significantly without sacrificing the quality of the results.
- Use a low External Heat Transfer Coefficient: Around $8.5 \text{ W/m}^2\text{-K}$ – The External HTC dictates the heat loss from the outside of the mold to the surrounding foundry air. This low value represents what would happen when the outside of the mold remains fairly cool. Only a small amount of heat convection and radiation takes place.
- Only use as much sand as is necessary to absorb the heat (2-3cm for small castings, 10-15cm for large castings) from solidification – Since most simulations are run until the casting is solid, it normally is not necessary to create a model of the full flask/mold size. Only enough sand is required to absorb the heat given off during the actual solidification process. This usually results in smaller models and quicker simulation times.
- Generally make a rectangular mold when meshing – The software package can automatically create a mold for you while meshing. This saves model building time. Rectangular or constant-thickness shell molds can be created instantly. A shell mold, if made thick enough, can actually run through a simulation most efficiently, since some of the nodes will be of ambient air, which do not require the full heat transfer calculations. Meshing a shell mold normally takes longer than a rectangular mold.

Investment Casting

- Turn off Internal Heat Transfer Coefficients – Thermal properties determine how heat flows THROUGH a material, while Heat Transfer Coefficients(HTCs) determine what happens at the INTERFACE between materials. In investment casting processes, the insulating properties of the ceramic shell mask the effects of what is happening at the casting-mold interface. By ignoring these small effects, simulations can be speeded up significantly without sacrificing the quality of the results.
- Use an External Heat Transfer Coefficient: Around $55\text{-}80 \text{ W/m}^2\text{-K}$ – The External HTC dictates the heat loss from the outside of the hot shell to the surrounding foundry air. This value is much higher than what would be used for sand casting, and represents what would happen when the outside of the shell remains fairly hot. Much more convection and radiation takes place than in the sand casting process.

- Use “Shell” option when creating the mold, or the ShellMaker Utility for a complex shell – In investment casting the shell thickness is important in how heat is released. As with sand casting, it is possible to automatically create the shell mold during meshing. The system will create a constant-thickness shell about the model, made of an appropriate material. The preheat temperature of the shell can be varied by the user. If a complex shell is required. For example, multiple layers of differing materials, or if an insulating wrap may be added later, then the ShellMaker Utility can be used to create an STL file of a constant-thickness shell. This file can be added directly to the model. If this method is used, then, at mesh time, no mold would be the selected option, since the mold is already a part of the model.
- Use Void Material as necessary to remove material from shapes – In sand casting, holes are made in the part using cores. In investment casting, holes are generally created in the wax pattern itself. A hole in a solid model can be created by making a ‘core’ of Void Material, which, during meshing, will replace the material with either ambient air or the shell material, whichever is appropriate.
- Use View Factor Calculations to take radiation into account – The External HTC is increased to show the effect of a hot shell, but it does not show the variation in radiation from different parts of the shell. Radiation is based on temperature difference, and, if two parts of a hot shell are facing each other, then the radiation heat transfer will be reduced. The View Factor Calculation looks at each shell position and adjusts the External HTC at that point, based on the ‘view’ at that point. For example, an internal pocket in the shell will see almost all hot shell, so will therefore have a low External HTC. On the other hand, a point on the outside edge of the shell will see mainly foundry air, so will therefore have a high External HTC. A view factor calculation is illustrated below in Figure 1:

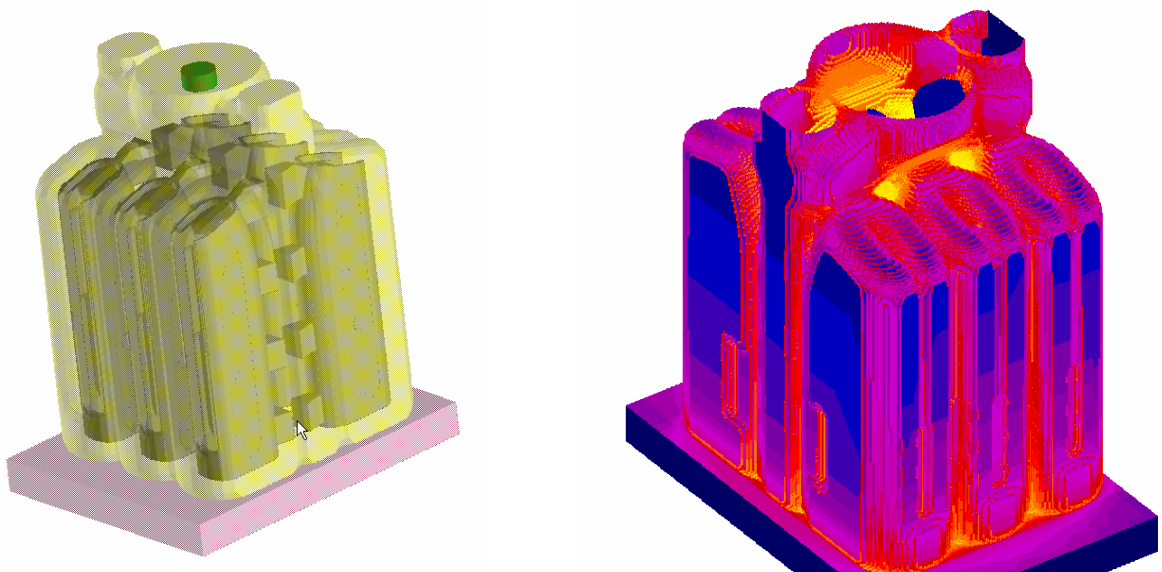


Figure 1. Investment casting tree in a sand bed(left), and radiation view factor calculation(right).

Gravity Die Casting

- Turn on Internal Heat Transfer Coefficients – Unlike sand and investment casting, in gravity die casting the die and die surfaces play a very important role in the overall solidification. Since the die is quite conductive, barriers to heat flow at the die surfaces, both where the casting makes contact and at the die/air interface must be taken into account. This is done by developing a table of HTC's for each interface. Utilities are available to calculate appropriate values to use in different situations.

Use of internal HTC's allows calculation of the following effects in gravity die casting;

Variable-thickness mold sprays
Water or Air cooling channels
Air gap formation at the casting/die interface

- Use an External Heat Transfer Coefficient: Around 30-40 W/m²-K – This value is intermediate between a sand casting and an investment casting, reflecting the die temperature.
- Use the HTC reducer function at the metal-mold interface – This function can be used to model air gap formation, when the casting solidifies and shrinks away from the mold wall. Research has shown that the effective heat transfer reduces to about 30% of original when a gap forms. By using this function, the system will automatically reduce the HTC at the metal-mold contact point, when that point reaches the solidification temperature.
- Use “None” option when meshing if the mold is part of the model – The die is normally a somewhat complex shape, so is often built as a part of the model itself. In this case it is not necessary to have the system create a mold during meshing.
- Use View Factor Calculations to take radiation into account – As with investment casting, a gravity die is much hotter than the surrounding air. This makes for radiation heat transfer. The View Factor Calculation will properly set the HTC's on the die surfaces, based on what other hot surfaces are visible at that point.
- Use Permanent Mold Cycling when running simulations – Since the die is not consumed during the casting process, it retains the temperature distribution from the previous casting cycle. Under operating conditions, the die will assume a pseudo-steady state, and will have a consistent temperature distribution at the start of each cycle. The die needs to be cycled a number of times in order to reach operating conditions. The software will start with a die at an initial uniform temperature, then calculate the filling and solidification of the casting. The part will be ejected, and the cycle will start again. Die open time can be accounted for, and simulations can be run for specific cycle times, or to full solidification to determine the ‘natural’ cycle time.
- Use the “Coarse”/“Fine” mesh option for warm-up cycles – During the warm-up phase of the simulation, the actual solidification pattern is not important. What we are mainly looking for is the heat input from the metal, which affects the temperature distribution in the die. By creating and using a coarse mesh for the warm-up cycles, the heating phase of the simulation can be done quite quickly, even with a fairly large number of cycles. The temperature distribution of the die can then be mapped onto a fine mesh, where the final filling and solidification cycle can be run for maximum accuracy. This process can speed up overall simulation results by up to 10 times, while still maintaining accurate simulation results.

Calibration of Data

Calibration refers to adjusting property data and other inputs so that outputs, or simulation results, most accurately reflect shop floor results. Since a simulation is a model, or an estimate, of the real world, results will not always exactly match shop floor experience. However, by making simple adjustments to property data, or to plotting ranges(sensitivity), it is quite easy to improve simulation results so that they match shop floor data very closely.

- Where to get property data – The software comes with both casting alloy and mold material databases that cover many applications, but of course neither database contains complete listings of alloys poured or mold materials used. There are a growing number of web sites that can provide extensive property data, either at no charge or for a yearly subscription fee. Probably the most often used free service is Mat Web (<http://www.matweb.com>) and a substantial subscription service is available from ASM International (<http://www.asminternational.org>). Often, by typing an alloy name into a web search engine will bring multiple sources of information. New data can be easily entered into the existing databases, for future use. As we collect new data, we periodically release new databases with the software.

If specific information is not available for a particular alloy, it is possible to use data from a known alloy of similar chemistry. In many cases the differences are small enough that results are not compromised. And, for some property data, such as specific heat, density and latent heat of fusion, good estimates can be made using a weighted average of the properties of the individual elements. This technique should NOT be used to predict thermal conductivity or freezing range, as it does not provide realistic results.

- Fine tune property data – When examining simulation results, you can make simple adjustments to property data to further improve simulation accuracy. In most cases, start with property data ‘out of the box’, as provided in the casting and mold material databases, or with data acquired from other sources. Thermal properties used in the software are constant, or average values, which do not vary with time or temperature. The simplest adjustment would be changing the pouring temperature, and this should be done with EVERY simulation to correspond with your own shop practice.

Another easy adjustment can be used if you have a known solidification time for a part. For example, if you know the solidification time is, say, 10 minutes, and simulation predicts an 8 minute solidification time, then you know that the mold is extracting heat too quickly. In this example, you could reduce the thermal conductivity of the mold by 10-20%, then run a new simulation. The new results should now be much closer to shop results. By making adjustments such as this, using a range of castings, you can quickly zero in on the best properties to use for your own processes and parts.

- Use built-in functions or known information to improve solidification/shrinkage curves – There are actually 3 different ways to create solidification and shrinkage curves in the software; Use system defaults, hand draw curves, and use built-in functions to create curves. These curves, along with thermal properties, control how heat is released and how shrinkage will occur. If nothing is known about an alloy, then using system defaults is the simplest method, and generally yields good results. The curves are simple straight lines, and solidification behavior is assumed to be linear.

In the case of aluminum alloys, research has been published that gives better information for many foundry alloys. This information is given in the form of a table, listing the percent solid vs temperature. With this data, it is easy to hand draw a solidification curve in the software. This work has already been done, and several curves have been hand drawn for the database.

For cast irons, even more data is available, in the form of built-in functions and system utility programs. These functions and utilities allow you to take a base alloy, adjust the chemistry, pouring temperature and section size, and see the resulting effects on solidification, shrinkage and critical fraction solid(CFS) point. Once these adjustments have been made, you can save the curves and properties as a new entry in the database. In this way a whole series of materials can be quickly created for specific situations, even though the base properties of just a few alloys are known. Examples of differing solidification curves and CFS points for ductile iron castings of varying section size are shown below, in Figure 2:

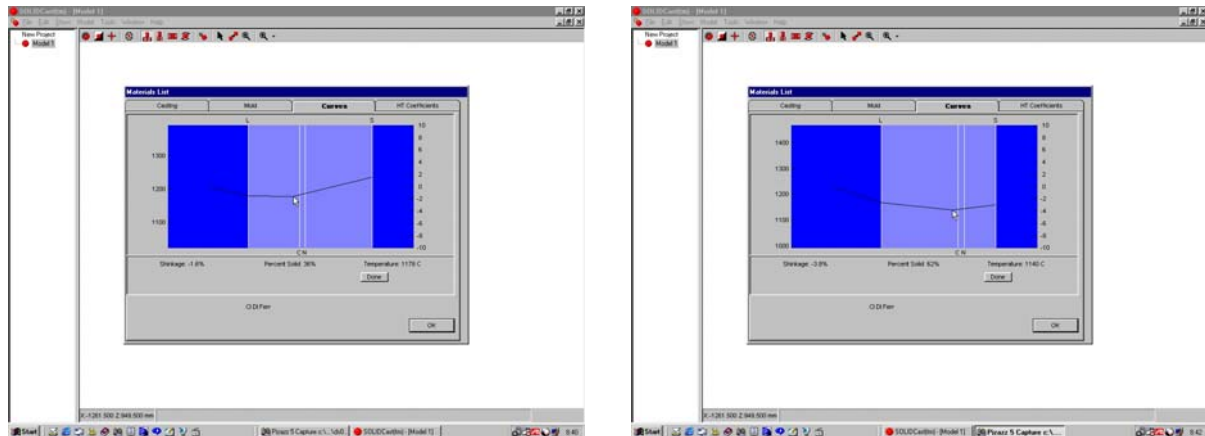


Figure 2. Solidification curves for light section(left) and heavy section(right) ductile iron castings.

- Adjust plotting ranges – Another way to fine tune the process is to change the sensitivity of a plot by adjusting the range used in that plot. For example, the Material Density function will normally range from 0-1, where 0 represents an area completely drained of metal, and 1 represents a completely sound area.

A good starting point for this plot is 0.99. That is, only display areas that have lost more than 1% of their nominal density. Experience has shown that this is about the point at which an indication would begin showing up on an X-Ray or radiograph. However, the exact values will vary between foundries, as well as with materials, processes and section sizes. So it becomes difficult to say ahead of time what values will work best in a given foundry. However, it is quite easy to adjust the range and re-plot. It only takes a few seconds. By plotting using several ranges, or sensitivities, then comparing with the shop floor results, you can quickly establish what range of plotting is most realistic for your operation. Expanding the plot range also has an added advantage of point out what areas will most likely be affected next, in the event of, say, an abnormally low pouring temperature, soft mold, or other processing defect.

Training

Training is the final area to concentrate on for simulation success. In my opinion, the best background for a person involved with simulation would be foundry engineering/methoding. Those individuals have an understanding of the solidification process and what the results of a simulation show. Learning the actual steps to running a simulation is comparatively easy, understanding the underlying processes is more difficult and takes more time.

Interestingly enough, running simulations is a great way to acquire a better understanding of metalcasting itself. By opening the mold visually during pouring and solidification, it is much easier to see what is going on, compared to the shop floor. This is one of the reasons why simulation software is quite popular at universities and schools. Sample simulations of various types can be very useful tools to help explain how metalcasting works.

The areas focused on in this paper are those techniques that can be used to make simulations more efficient. In general, these techniques result in faster simulations, without degrading simulation quality. In some cases, however, results may be suspect. In those cases, simplifications should be done only during initial stages. Confirming runs should always be done in the more 'rigorous' mode, to ensure simulation accuracy.

- Use Planes of Symmetry and Mirroring Wherever Possible – Many castings, or pattern layouts, contain symmetry, or mirror images. By using a plane, or planes, of symmetry, you can run simulations 2-4 times faster, without affecting simulation results. Once the simulation is complete, data can be mirrored to the full model, so plotting and movie making can still make use of the full model or pattern layout.
- In Model Building, Create Only the Necessary Parts – For example, if running a simple filling simulation, rather than a full CFD-based fluid flow analysis, you normally won't have to create the complete gating system. In most cases, the mold can be created automatically at mesh time, rather than built as a part of the model. Examples of models appropriate for simplified filling and full CFD fluid flow analysis are shown below in Figure 3:

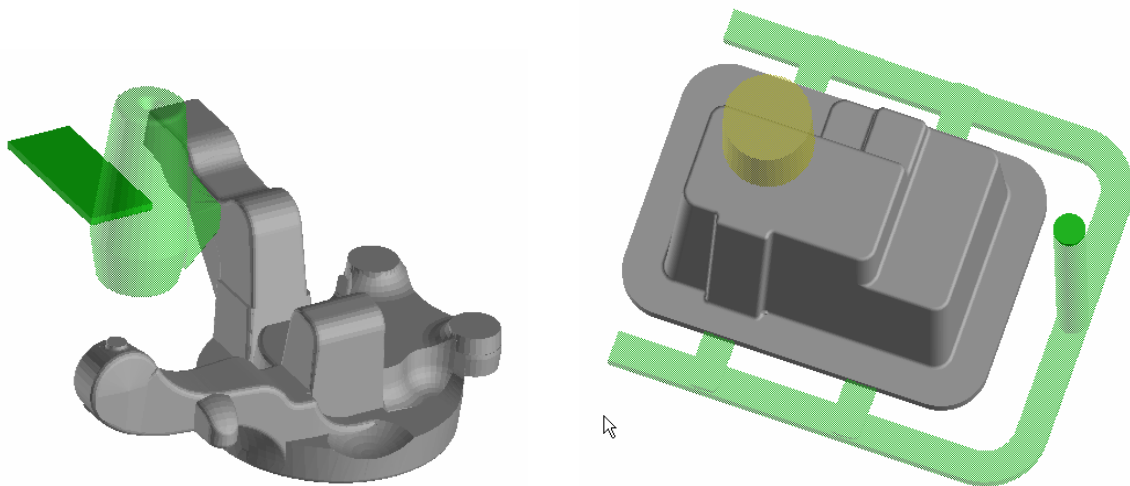


Figure 3. Simplified mold filling model(left), complete model for full CFD fluid flow analysis(right).

- **Run Simulations Only as Long as Needed** – If you are analyzing results in the casting, it is not necessary to run a simulation to full solidification of gates and risers. By letting the system finish when the casting is solid, you may save 30-40% in simulation time. This is very important when running an automatic process optimization, as the system may actually run as many as 100 individual simulations.
- **Let Simulation Help Design Your Rigging Systems** – The Gating and Riser Design Wizards were developed to help you to find the best rigging possible as quickly as possible. Most simulation packages, if used properly, will yield reasonably accurate results. However, simulation results, on their own, will not tell you how to rig a casting! They only show you what would happen in that given situation. The Gating and Riser Design Wizards actually use simulation results for an unrigged casting to guide you through the rigging process.

Once the casting has been rigged, you can run a confirming simulation, to verify that the results are acceptable. If need be, you can fine tune the system, or submit that design to automatic process optimization, which can do the fine tuning for you, based on your own quality criteria. This technique actually reduces operator effort in simulation and improves simulation and foundry results at the same time!

- **Start Coarse, End Fine** – When running an initial simulation, you can usually run it with a low number of nodes, or with a coarse node size. This reduces the number of calculations and speeds simulation results. As you near your final result, you will want to increase the number of nodes or reduce the node size. This gives the best part representation and ensures simulation accuracy. In some processes, such as gravity die casting, you can actually automate this process, using a coarse mesh for warm-up cycles, and a fine mesh for operating conditions.

Conclusion

Casting process simulation software has become an accepted part of the foundry engineering 'toolbox' over the past 20 years. While not a substitute for sound engineering knowledge and background, software can make an engineer more efficient and can lead to a better understanding of the metalcasting process. By paying special attention to software setup for specific processes, by doing simple data calibrations in the foundry and by taking advantage of training opportunities, implementation of simulation software can be quick, efficient and cost-effective, even for the smallest shops.