

From “Naked” to “Dressed” – A Case Study of Casting Rigging Via Computer Simulation

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Abstract

This paper focuses on the practical approach of rigging steel castings using computerized casting simulation. While software has been commercially available for over 20 years to simulate the pouring and solidification of castings, it has mainly been used to ‘test’ rigging systems that have been developed using traditional shop floor trial and error methods. Only recently has software developed to the point where simulation can be actually used to design the methoding, not just test it.

This process involves running an initial simulation on a ‘naked’ casting, that is, a part without any gating or feeding system. Results from this analysis are then used directly by the system to determine feeding zones on a part and design risers to supply the appropriate amount of feed metal to prevent shrinkage in those feeding zones. Casting alloy, mold material and feeding practice are all taken into account. Once risering is designed, the gating system is also developed, using actual simulation results, so that very little operator time and effort is required. Appropriate pouring times are determined, along with the dimensions of the downsprue, runner(s) and gate(s), so that the castings will fill in an optimum fashion, based on casting size and critical section thickness. If a bottom pour ladle is used, the system can also supply critical information to insure proper filling time and speed.

The fully rigged model is then built and verified using full CFD-based fluid flow analysis and combined thermal-volumetric solidification analysis. Verification simulations assure that the rigging system will perform as advertised; that is, fill the mold in an appropriate way and provide good temperature gradients for directional solidification and a sound casting. If desired, the verified model can also be submitted to automatic casting/process optimization analysis to maximize the efficiency of the method, without sacrificing casting quality.

A detailed case study will be used to demonstrate how this process is successfully applied on a daily basis in the foundry. Examples will also be shown of advancement of hot tear predictions in steel castings.

Introduction

Correct design of gating and feeding components for castings is essential for a foundry to be successful in the production of high-quality castings. In today's environment where customers demand that the lead time for new parts be as short as possible, foundries who can produce sound castings from the very start have a distinct advantage; proper rigging system design is the key to making this happen.

Design of efficient gating and feeding systems for steel castings has been difficult for foundry engineers due to a number of factors. Chief among these is the complex geometry of many commercial castings; while there have been well-established design rules for a number of years, the application of these rules to a variety of commercial casting shapes typically involves cumbersome calculations that, when performed manually, require a number of simplifications to reality. These approximations can reduce the accuracy of the resulting designs. Even when rigging calculation methods are used, if the work is not integrated with a simulation tool, extra effort is needed to perform the calculations and the data used is not nearly accurate as simulation results themselves, which take into account such things as casting alloy, mold materials and the like.

With the advent of sophisticated software simulation systems in recent years, it has become possible to synthesize a number of the elements of good rigging design into a general method that is fast, thorough and highly accurate. This method overcomes many of the difficulties listed above. In addition, because of the automation involved, this method allows foundry personnel who may have limited experience (e.g., new foundry engineers) to effectively design casting process methods. In the past, some foundries have experienced major problems when experienced designers retired from the workforce; an automated design method lessens the impact of such an occurrence.

The Design Process

The general design process consists of the following steps:

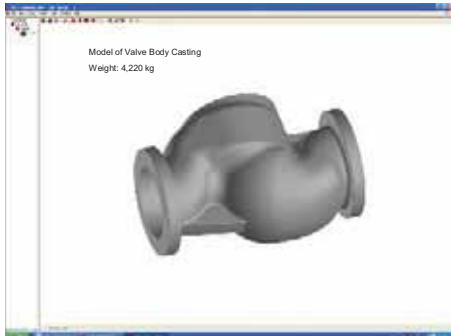
- Simulation of the 'Naked' Casting
- Feeder Design
- Gating System Design
- Rigging Geometry Creation
- Verification via CFD/Solidification Simulation

The balance of this paper will demonstrate these steps, using a valve body casting, typical of many commercial castings produced today. There will also be a short section demonstrating recent advances in hot tear predictions using simulation.

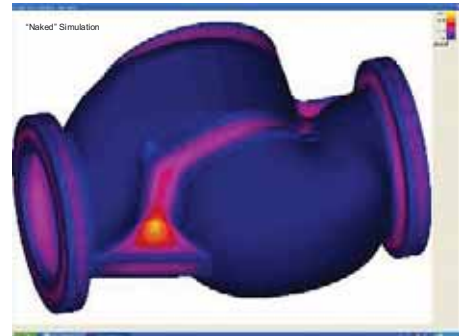
“Naked” Simulation

The first step in the rigging process is to run a simulation of the part ‘naked’; that is, without any rigging system. Simulation results show the effects of the part geometry on the overall solidification. In this initial simulation, filling analysis is typically not done, which provides extremely rapid results, and can point out preferred gate and feeder locations which would promote directional solidification.

All that is required for the initial simulation is a casting model, normally provided by the customer in STL file format, and basic process details such as casting alloy, mold material and pouring temperature.



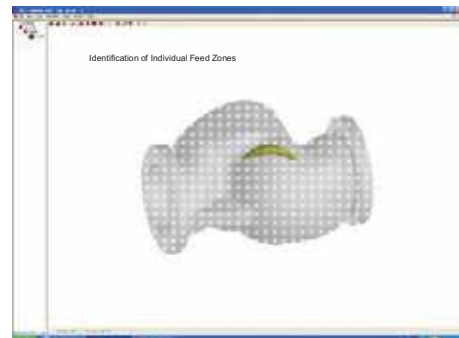
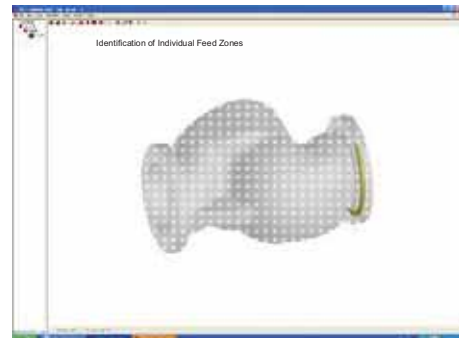
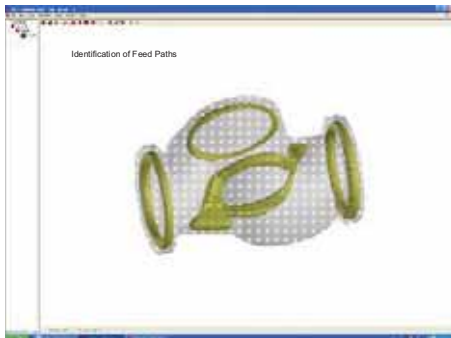
Left, STL model of a valve body casting.



Right, ‘naked’ simulation results, without filling.

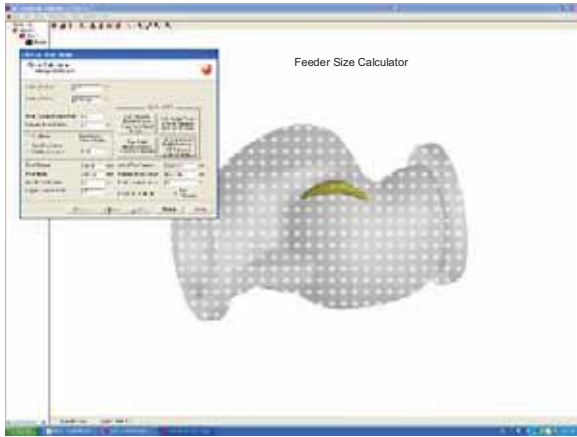
Riser Design

Once the initial simulation is complete, the data from the simulation can be used to design the rigging components. The feeders, or risers, are typically designed first, followed by the gating system. The software uses the progression of solidification, along with a pattern recognition algorithm, to determine the separate feeding paths on the casting, as shown below. Further, the software can find the last points to freeze on each feeding path, which will be the preferred feeder contact points.



Feeding paths on the valve body casting, along with last points to freeze in various feeding zones.

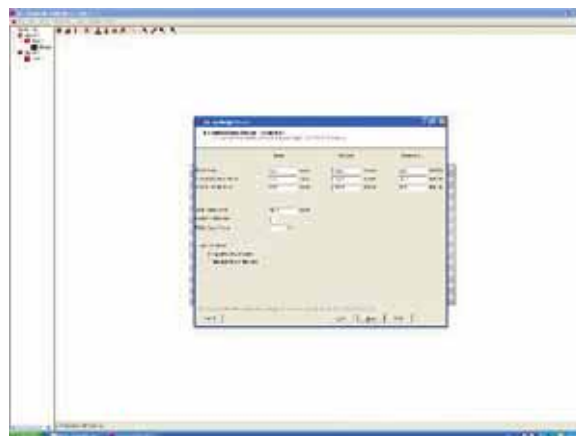
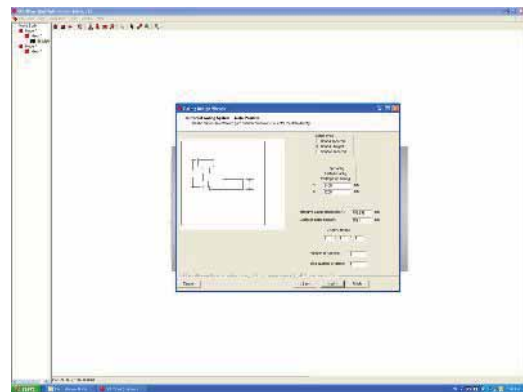
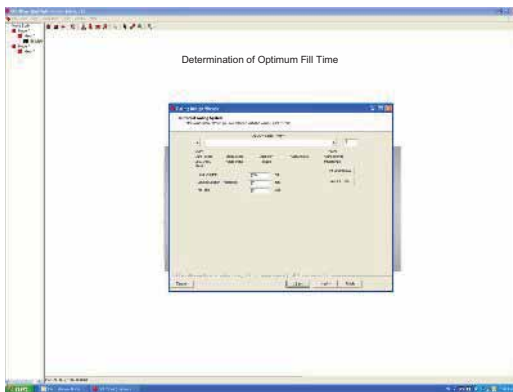
Feeder sizes for each feeding zone are calculated by the software using variations on the well-known Modulus Technique. Solidification time information from the initial simulation is converted into a 'thermal modulus'. This takes into account not only casting alloy and mold material, but also the solidification dynamics of the specific mold situation. Feeding aids, such as insulating or exothermic sleeves, can be accommodated in the calculation.



Feeder size calculations.

Gating System Design

After all feeders have been calculated, the next stage is to design the gating system, to bring the metal into the mold efficiently. Calculations are based on both Bernoulli's Theorem and the Law of Continuity. All components of the gating system are calculated, including sprue, runners, gates, etc. Sample screens from various points in the gating calculation are shown here:



Gating system component design.

If bottom pour ladles are used, filling becomes more complex, as the pour rate will vary continuously as the metal is discharged from the ladle. As the metal level in the ladle decreases, pouring rate will also decrease. The system can calculate a proper nozzle size for a given ladle geometry and metal amount, to insure that calculated pouring times predicted by the system will be achieved on the shop floor. This data is also fed into the CFD analysis to perform a variable rate mold filling simulation.

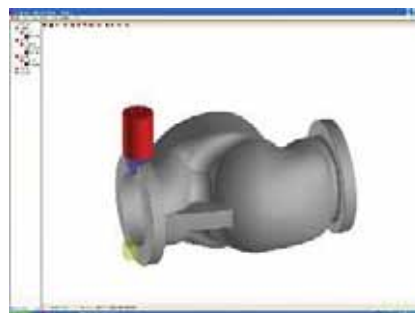
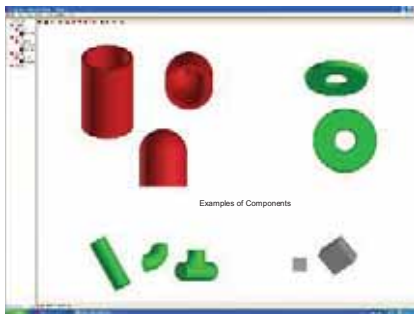


Bottom pour ladle calculations.

Modeling the Gating and Riser System

Gating and feeder calculations, as outlined above, will normally take only a few minutes to perform. The output is a spreadsheet of component dimensions that can be used to create geometry in a CAD system, or in the software model builder itself.

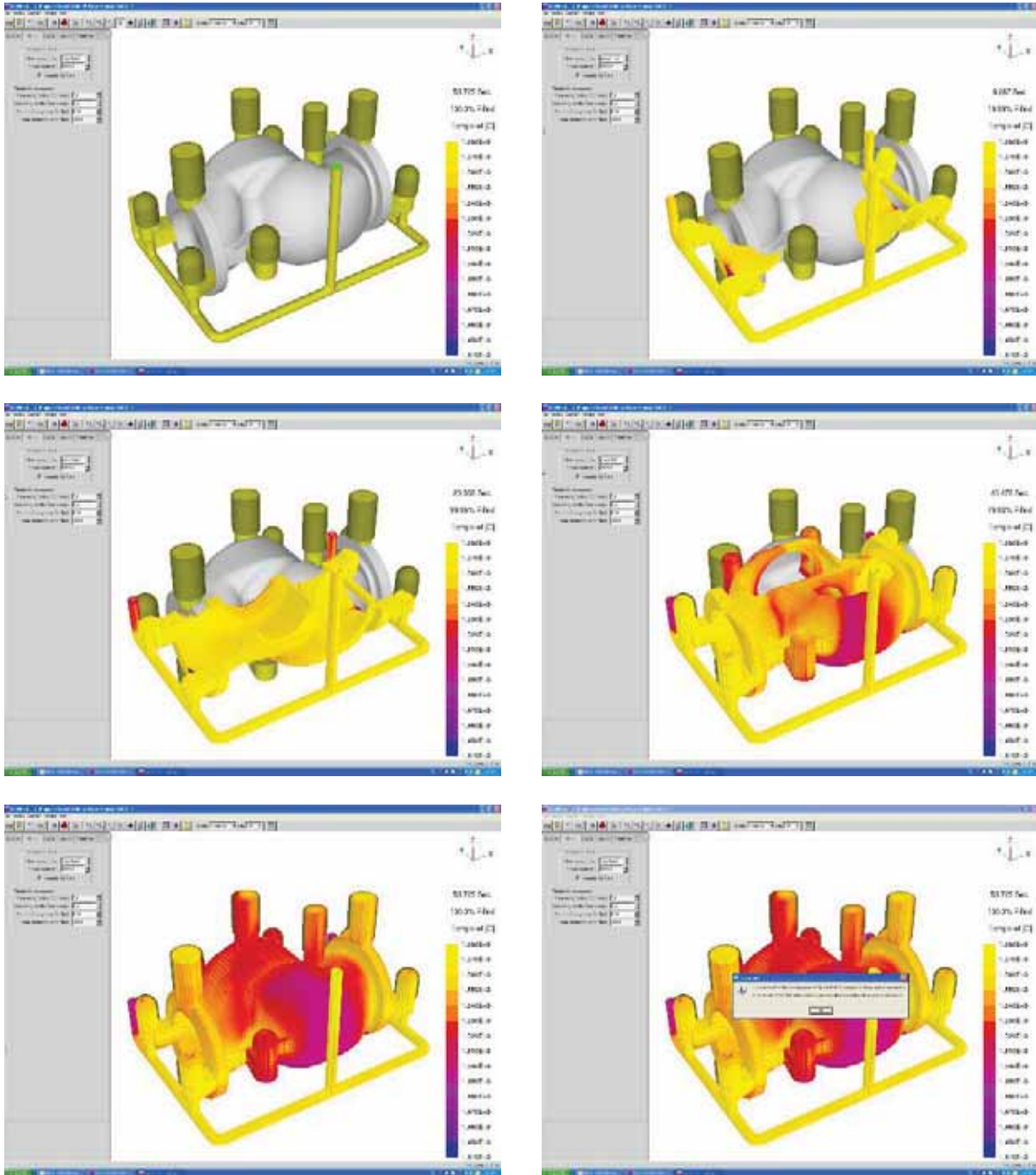
Many gating and feeder components are used on many different castings in a given foundry. For example, a foundry may have a series of standard sizes of downsprues, or use specific sizes of riser sleeves. These types of components can be created once in CAD, then saved and reused in any model in the future, without having to re-create the geometry each time. If a library of gating components is developed and used, the entire gating and riser design process, from loading the unrigged model to having a fully rigged geometry ready for verification simulation, can be as short as 30 minutes or so. Addition of a chill and riser to the valve body casting, using components, is shown here:



Riser and chill added to the casting model using component parts.

Design Verification Using CFD and Solidification Analysis

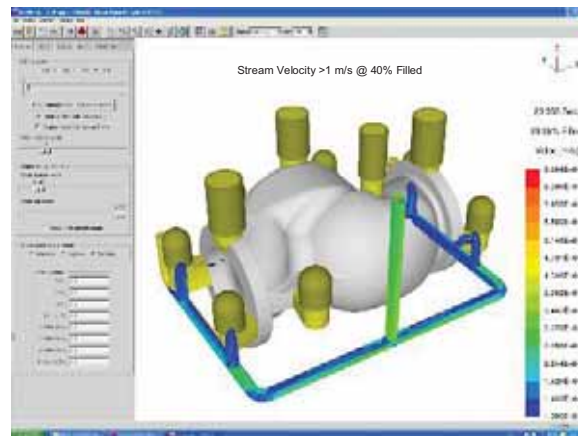
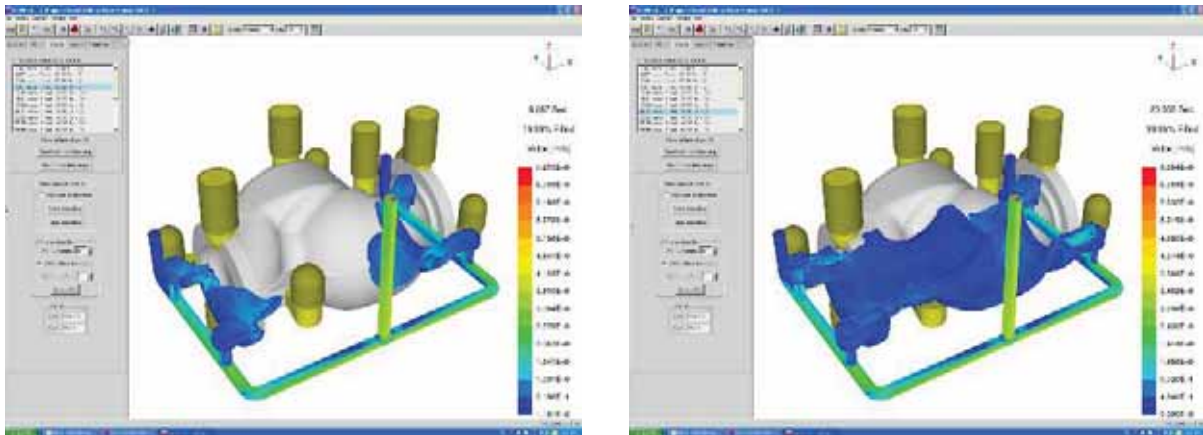
Once the rigging system is in place, a full Computational Fluid Dynamics(CFD) analysis is performed to accurately predict and visualize mold filling. This also provides the most accurate temperature distribution in the casting and mold, which, in turn, provides a better solidification analysis.



Temperature distribution during mold filling. CFD analysis shows positive temperature gradients that promote directional solidification.

In addition to temperature analysis, CFD can provide velocity information. It is important to keep metal stream velocities low during filling, to minimize chances for splashing, mold erosion and re-oxidation defects. The plots on the following page show how this information can be used. The first two figures show low stream velocities at the early filling stages. The third figure shows a plot at 40%

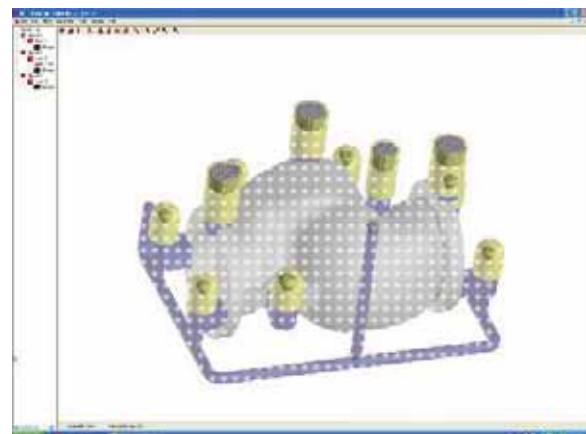
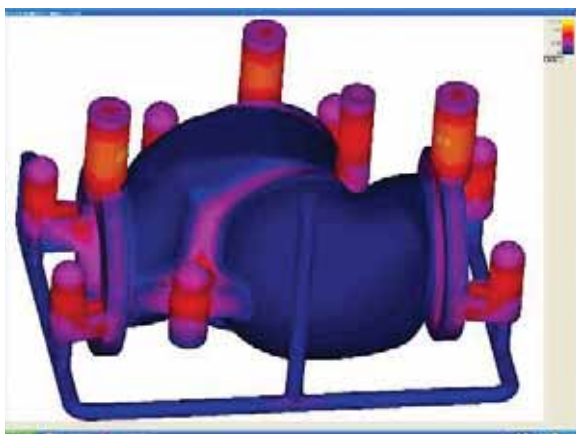
full, with a minimum value of 1.0 m/s. Since the casting is 'clean', this means that all metal movement in the casting is below 1.0 m/s.



Plots of metal stream velocities during filling.

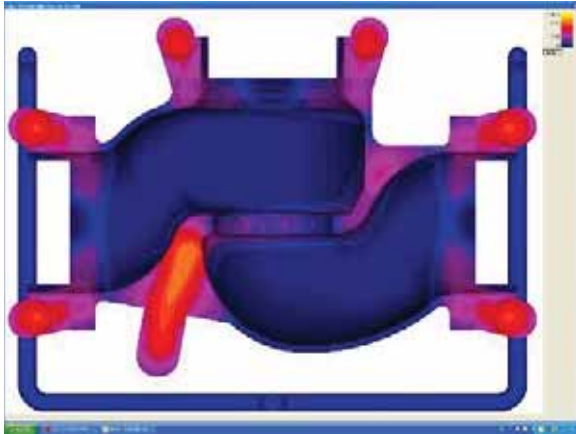
Filling analysis is automatically followed up with solidification analysis, using a combined thermal and volumetric calculation. This technique not only predicts poor directional solidification, but provides the most accurate analysis of macro-shrinkage due to volumetric feeding from the risers.

The figure on the left below shows the progression of solidification and the figure on the right, volumetric feeding of the risers. The 'piping' of the risers is displayed by plotting where the metal has lost 10% or more of its' density due to volumetric feeding.

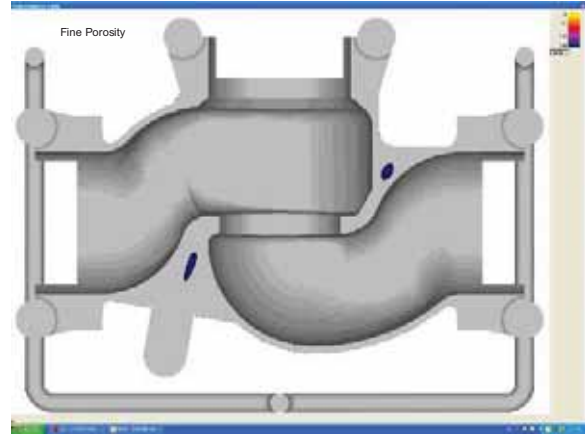


Left, solidification progression on the rigged casting. Right, volumetric feeding of the risers.

The two figures below show sectioned views of the casting near the parting line. The figure on the left shows the progression of solidification, based on the Critical Fraction Solid(CFS) Time, which is a measure of the end of volumetric feeding. Notice that there are two bright spots in the casting. These areas were caused by the addition of feeders in the areas and the mold filling dynamics. The figure on the right shows two indications of very fine porosity in the web sections. Since these areas are not in the sidewalls of the part, they are acceptable for this type of commercial casting.



Left, progression of CFS Time.



Right, low level porosity in web sections.

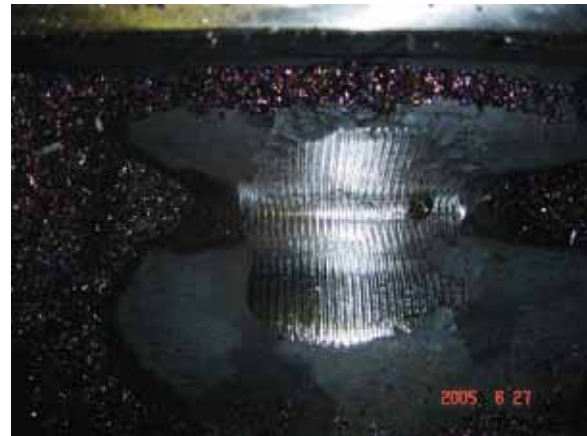
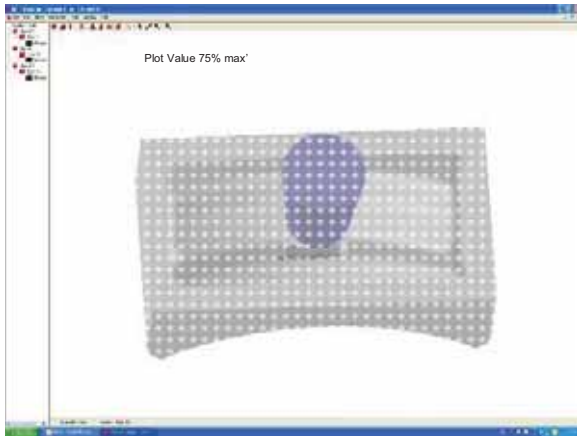
In many cases, the design portion of the analysis can be done in an hour or less. Verification simulations, using full CFD analysis, can be done typically in about two hours to overnight. Simulation times will vary depending on such things as computer processor speed and available memory, casting complexity and materials cast. In general, thinner walled castings require more computation time, and materials with higher thermal conductivities, such as aluminum and copper, will also take longer to simulate, all other things being equal.

Hot Tearing Indication

Hot tearing is a problem that often plagues the steel founder. Thermal stresses built up during pouring and solidification can cause huge difficulties, especially in alloys with longer freezing ranges. If these mushy freezing alloys do not develop a strong outer skin early in solidification, then the increasing stresses can cause tearing and cracking to occur.

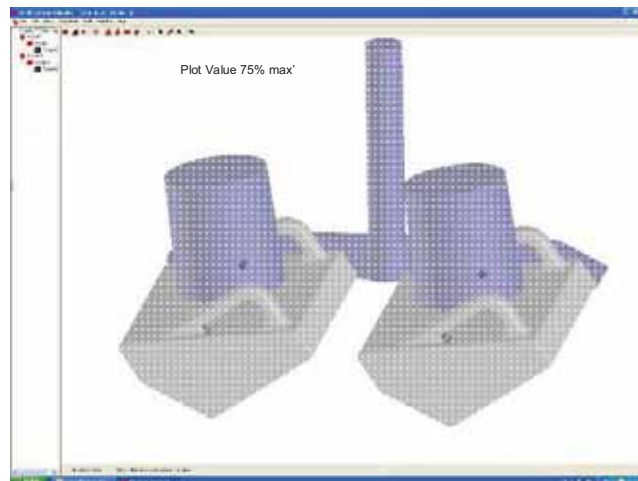
While absolute prediction of cracking and tearing is virtually impossible, location of crack-prone areas and the relative magnitude of the problem can now be successfully done. The technique used is to calculate the 'Solidification Time Gradient' (STG) at each point in the casting. This is a measure of the change in solidification time per unit distance everywhere in the part. Initial work was done with a generalized gradient calculation tool, which could be generally applied to any simulation output data, but experience showed that the STG gave the best correlation on models when compared to shop floor results. When applying the function, it seems that plotting at about 75% of the maximum calculated value produces the most realistic indications.

The figures on the next page illustrate this new function particularly well. The first figure shows a cast steel Slide. When plotting the STG at 75% of maximum, you can see an indication directly under the riser. The photo on the right shows the actual tear location in the same spot.



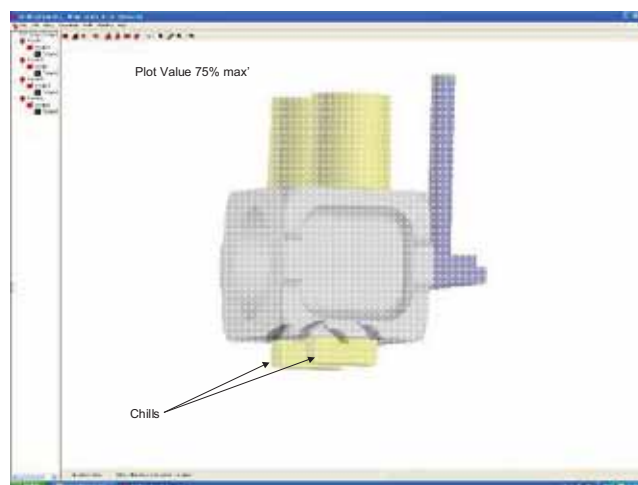
Left, slide casting, with under-riser tear indication. Right, photo of actual casting, showing the tear.

The second example, shown below, is an Inlay casting. The tear prone area is at the corner of each of the handles.



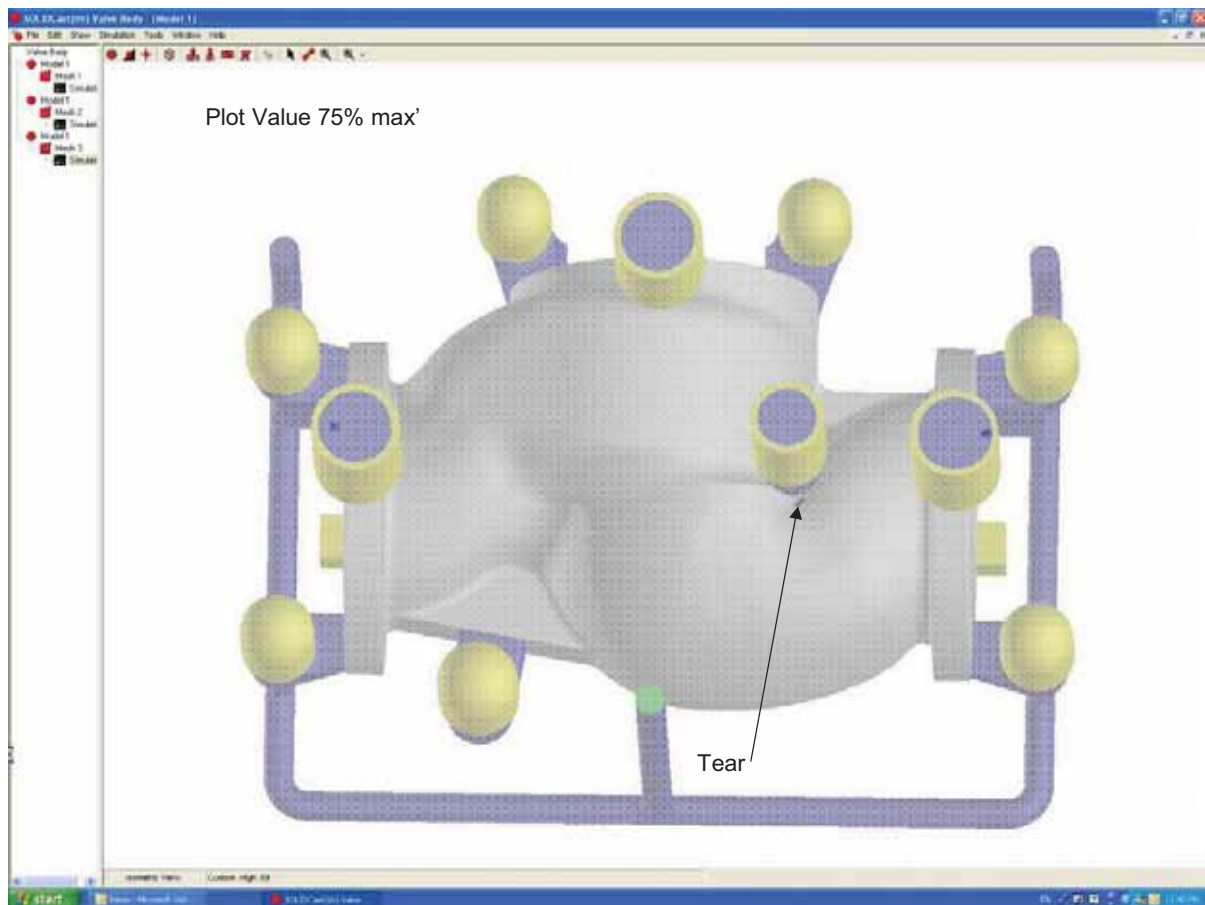
Inlay casting, with tear potential in handle corners.

The third example is a Block casting, with two chills on the bottom casting face. Tearing is a common problem associated with chills, due to the rapid solidification and subsequent contraction across the chill surface.



Block casting. Tear potential is at the chill corners.

The final example is our valve body casting, with full gating and risering attached. The indicated location of high tear potential is very typical for this sort of casting.



Valve body with tear potential under a riser.

Conclusion

Casting simulation software has gradually evolved from a problem detection or verification tool to an integrated part of the design method process. Simulation is no longer used to check a gating and risering system, but to actually be the driving force for the design of a rigging system. Even complex geometries can be successfully rigged in a short period of time using such tools.

The use of actual simulation results directly in the methoding process produces a more accurate result than manual techniques, and does it in a much shorter time period. This integrated approach reduces overall costs and reduces lead times. A valve body casting case study was presented to provide a detailed example of how such a tool is applied to commercial castings.

Several additional examples were given to show new capabilities in the prediction of castings that would be prone to hot tearing and cracking. The Solidification Time Gradient (STG) has shown to be a useful indicator of tear potential in steel castings.