Investment Casting Simulation

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In the current environment, investment casters need to stay on the cutting edge of new technologies to remain competitive in the marketplace. The capability to produce investment casting components of high quality while at the same time reducing product costs and development times is the challenge the foundry industry faces today. Increasingly complicated parts are being made through the investment casting process with less castable alloys. Computer aided modelling has been helping the foundry industry for the past several years, not only with the design of new components, but also in the redesign of existing products. By eliminating product defects and reducing scrap and rework, the investment caster can achieve improvements and more consistent product quality and obtain higher yields.

Even though computer aided process simulation has been available for the past fifteen years, many investment casters still use the conventional trial and error approach for process development. In many foundries, new cast components are often put together in different departments working independently of each other. When a new customer's need is identified, the design group generates the part drawings. The engineering department then identifies the mechanical stability and establishes guidelines for finalising the design of the component. Finally, the foundry brings the component into production, conforming to the stringent specifications provided by the designers. Inevitably, the foundryman is always under tremendous pressure to produce excellent castings within a tight schedule and budget. Unfortunately the traditional approach rarely allows the foundryman to participate in the design and engineering phases prior to the costly production stage.

In recent years, thanks to advanced computer aided technologies and casting process modelling, the traditional approach is becoming a thing of the past. Process Simulation provides valuable information that facilitates participation by the foundry engineer early in the product development stage. This reduces the time between the concept stage and production stage in the life of a new component.

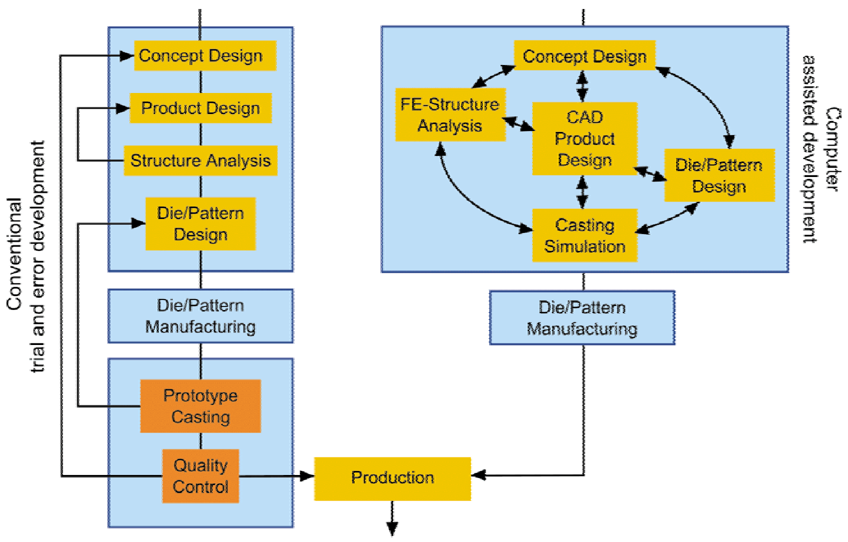

Figure 1: Trial and error development versus Computer Assisted Development.

Computer simulation has also proven to be an effective educational tool in the foundry industry. The goal is to accurately model all of the underlying physics of the process so that important process variables may be identified and effectively controlled. By visualising the entire casting process in a virtual environment, problems associated with fluid flow, solidification and part distortion become apparent to the designer and foundry engineer. Simulation also allows the testing of novel component designs and process modelling techniques, along with re-engineering designs in the early stages of development. Within the traditional approach, this would be undesirable due to the high cost associated with trial and error on the production floor.

In order for computer aided modelling to be successfully implemented into the design stage, it should perform a wide variety of tasks. Process simulation must have the capability to accurately model the properties of a wide range of casting alloys. Also, the nature of investment casting products can pose several difficulties to the modeller. Due to the highly complex nature of the investment casting part and gating design, especially in the aerospace industry, the software has to accurately model the process in order to be of any significant use to the foundry engineer. The predictions which are derived from modelling strongly depends on the ability of the software to model the heat loss in the mould. Since the cooling of the mould in an investment casting process primarily takes place through radiation, view factor calculations must accurately predict the self-radiative effects in all areas of the casting assembly. The casting solidifies by cooling though contact with the ceramic mould. The contact conductance varies with geometry and time. Further, to realistically model the whole process, the material data supplied should be at elevated temperatures describe the thermal behaviour of the material in the mushy state.

Highlighted in this article are some case studies for the investment casting process. In some cases, the original casting design produced poor quality castings, others had low yield. Analyses were performed using the *Procast*™ simulation software to modify the existing design, producing sound castings and improving part yield.

Part 1: Locking steel jaws for freight trailer

Trapped air and shrink porosity contribute to the majority of investment casting defects and rejections. The placement and design of gates and feeders are a critical step in controlling the last areas to fill and reducing part defects. This casting had a high reject rate in the existing set-up. Instead of redesigning the mould several times in trial-and-error fashion, the gating was redesigned with the assistance of computer modelling.

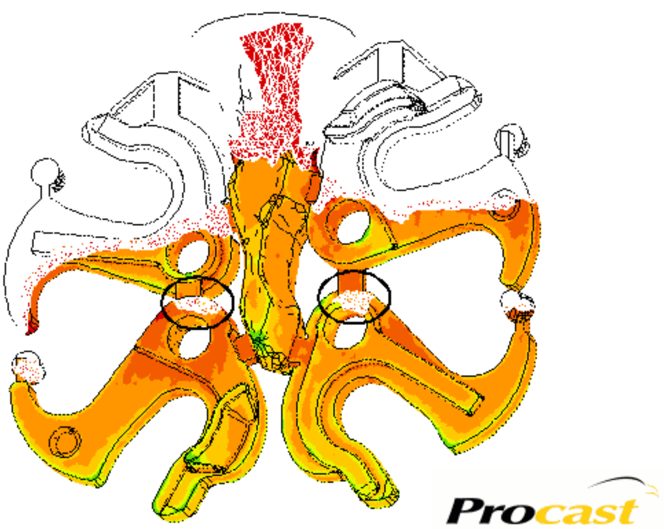

Figure 2: Initial tree layout design, highlighting air pockets.

In a complex investment casting cavity layout, a simulation tool like *Procast*™ proves to be an invaluable asset to understand the metal flow pattern into each cavity. Normally in such components, an investment caster would like to fill the mould in a unidirectional manner. Figure 2 shows the filling sequence of the metal arriving into the four cavities in a particular order. As seen from the picture, the metal first enters in the bottom two cavities. Even before the bottom two cavities are filled, the top two gates open up and metal begins cascading into the bottom cavities though the connection between the top and bottom cavities. This does not allow all the air and gasses to escape, leaving an entrapped pocket of gases. With no path out of the mould, these pockets will turn up as gas porosity defects in the final component. (Figure 3).

Figure 3: Air/Gas entrapment locations.

The other problem observed was shrink porosity in solidification. As seen in the X-ray plot, the improper feeding mechanism in the model produced three regions that were found to have porosity. This can be seen in the porosity plot (Figure 4) in the *Procast*™ results. Thus all the problems observed in the actual production environment were identified in the computer simulation.

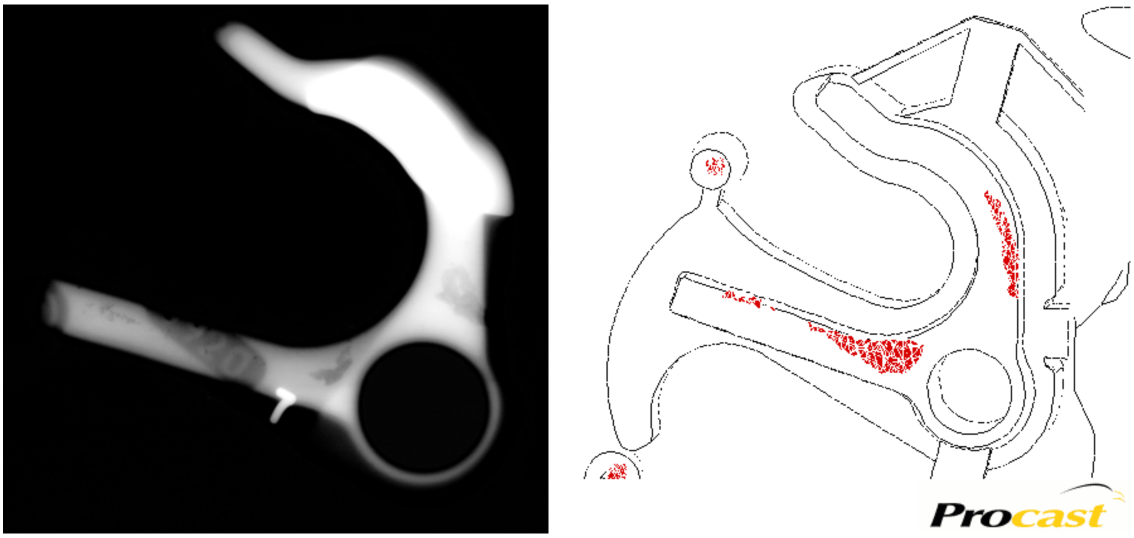

Figure 4: Shrink porosity defect as shown in the X-Ray and analysis.

Upon determining the causes of these defects, a new design for the gating layout was suggested. Instead of the tree set-up observed in the initial design, a flatbed layout was implemented. Computer simulation was performed on the new layout to identify any potential problems associated with air entrapment and shrink defects. The computer simulation showed a much better fill pattern without any air/gas porosity entrapment possibilities. The shrink porosity reduced significantly. The new design was then put into production and a remarkable improvement was observed in the quality of the casting.

Part 2: Stainless steel implant model

Designing the set up and orientation of investment cast parts requires a delicate balance of maximising the number of parts produced with a single pour while minimising part congestion, which leads to defects. For any single job, a virtually infinite number of combinations exists in varying number of parts, part orientation, and gating and runnering. The process engineer must rely on previous jobs in order to guess a set up that will produce quality parts. At best, this set up is not optimised to provide the highest yield. At worst, this trial-and-error method of design will produce defective parts.

Using casting simulation software, this guesswork is eliminated. Problems due to filling, part cooling and effects of neighbouring parts, and solidification are all identified and able to be corrected before the first pour. The following example presents an improper feeding issue being solved early in the design process, reducing the overall project time and without wasting material.

This project involved the production of medical implants. The foundry goals included production of the parts at a high rate with high quality and precision. Therefore, each pour had to produce a large number of defect-free implants. To meet these requirements, a “tree-type” set up was used with four runners. Due to heat transfer and solidification concerns, 24 parts were placed on the tree in a staggered formation to reduce part congestion. This design idea was then analysed using *Procast*™, which accurately calculated the effects of fluid flow, self-radiation and solidification.

The initial design showed that due to the filling order and self-radiation effects, there would be shrink defects in many of the implants. The filling order supplied hot metal to extremely varied locations in the cavity, affecting feeding and heat transfer rates. The location of the part on the tree greatly affected the size of the defect. Due to self-radiation, those parts in the centre columns suffered larger defects as the surrounding parts kept the large bulky head hot, as shown in the shrinkage porosity indicator of Figure 5.

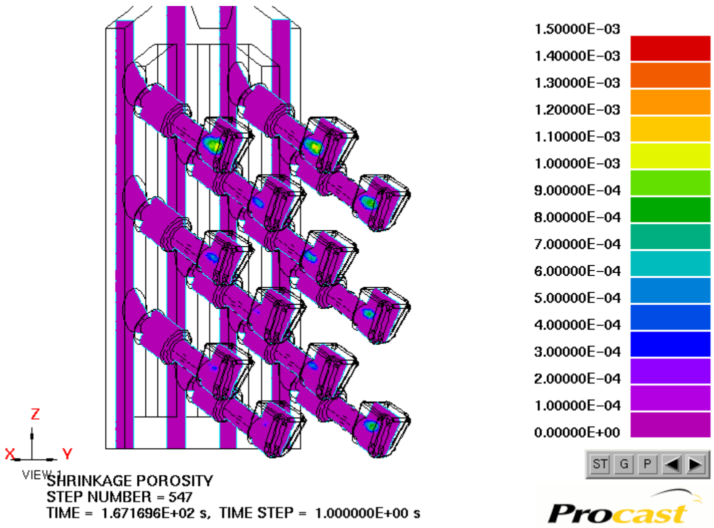

Figure 5: Potential porosity locations in original design.

The bulky sections of the implants tended to hold heat much longer than the rest of the part; therefore, feeding paths back to the gate were cut off prematurely, producing shrink defects. The fraction solid plot in Figure 6 shows this affect. The solid metal (grey) encloses the hot metal (red).

There were two primary solutions for improving the part quality, reduce the number of parts on the tree, thereby eliminating self-radiation effects which were keeping some of the parts way hotter than others depending on their position on the tree, or increase the gate size to keep the feeding path open longer. Obviously, reducing the number of parts in the set up drastically reduces efficiency per pour. Therefore, the gate size was moderately increased.

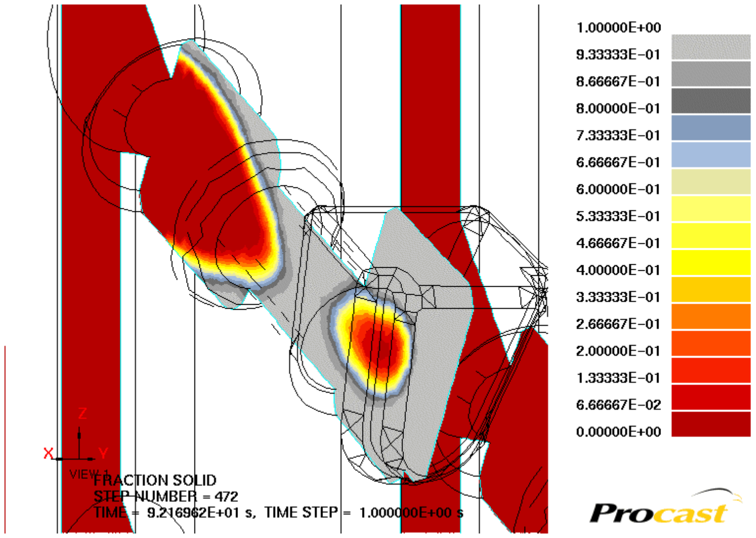

Figure 6: Solidification plot for original design.

The resulting analysis from this modified design showed the increased gate effectively kept the feeding path open. Figure 7 presents the fraction solid through the implant. The continuous path of hot (red) metal indicates an open feeding path, eliminating the shrink porosity, as shown in Figure 8. This increased gate also provided a more consistent filling pattern from the bottom of the tree upward, reducing spillover and splashing effects.

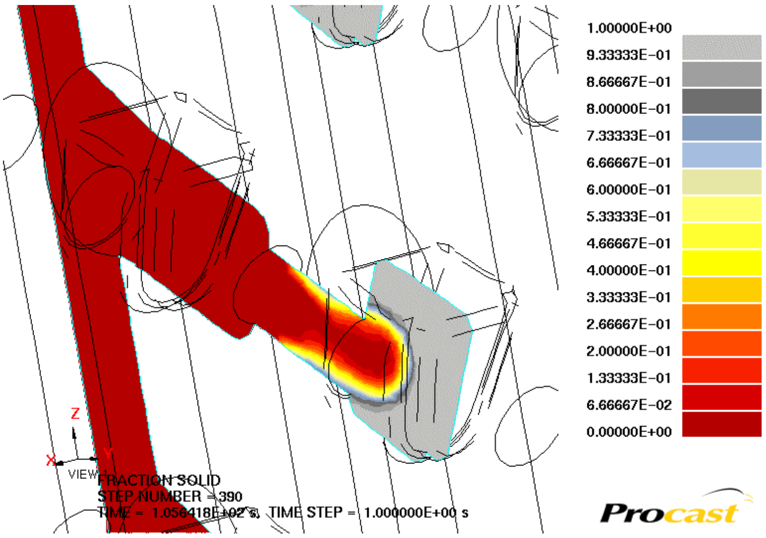

Figure 7: Solidification plot for modified design.

This project demonstrates how, in a very short period of time, computer modelling displayed the problem with the original casting design and verified a new design concept, which eventually lead to a better solution. Verification using simulation requires much less time to achieve a quality result and with no material costs rather than depending on the conventional trial-and-error methods on the production floor.

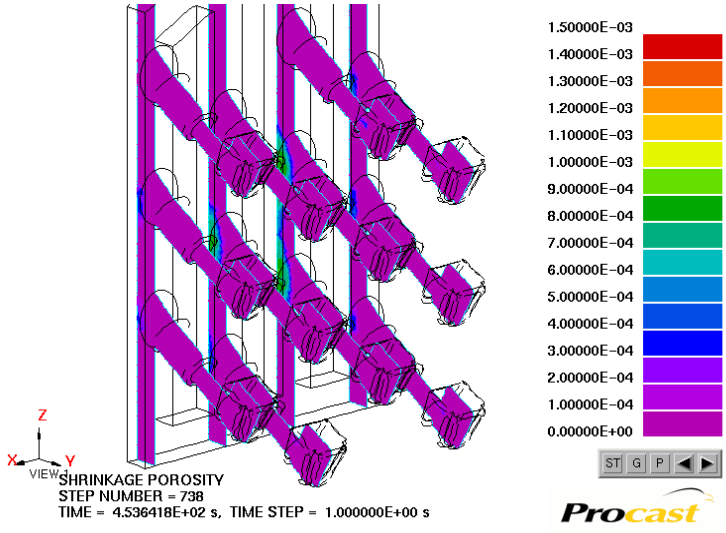

Figure 8: Potential porosity locations in modified design.

Part 3: Wax injection modelling

It is common knowledge that the investment casting process or "lost wax process" starts with a wax pattern. It is created by injecting wax into a mould cavity, where the pattern is an exact copy of the cast part with strict dimensional tolerances. It also has to allow for shrinkage of the material to be cast. This pattern is then dipped into a silica slurry bath. For a good surface finish, finer slurry and zircon sand is often used. The shell is then heated to dewax the mould, followed by firing and preheating before the molten metal is poured into the dewaxed cavity. A good understanding of the wax injection process is essential for good quality parts to be created. If there is a problem in putting together a good wax pattern, the final product will be adversely affected. Several tools are available to model the actual mould filling and solidification of the cast alloy, but few acknowledge the importance of modelling the wax injection process.

In order to model wax flow, a specialised solver must be used to accurately calculate the highly viscous wax material filling the pattern cavity. Figure 9 shows the wax injection process being modelled in the *Procast*™ software. The figure on the right shows that there is excellent agreement between computer predicted flow and the actual flow pattern.

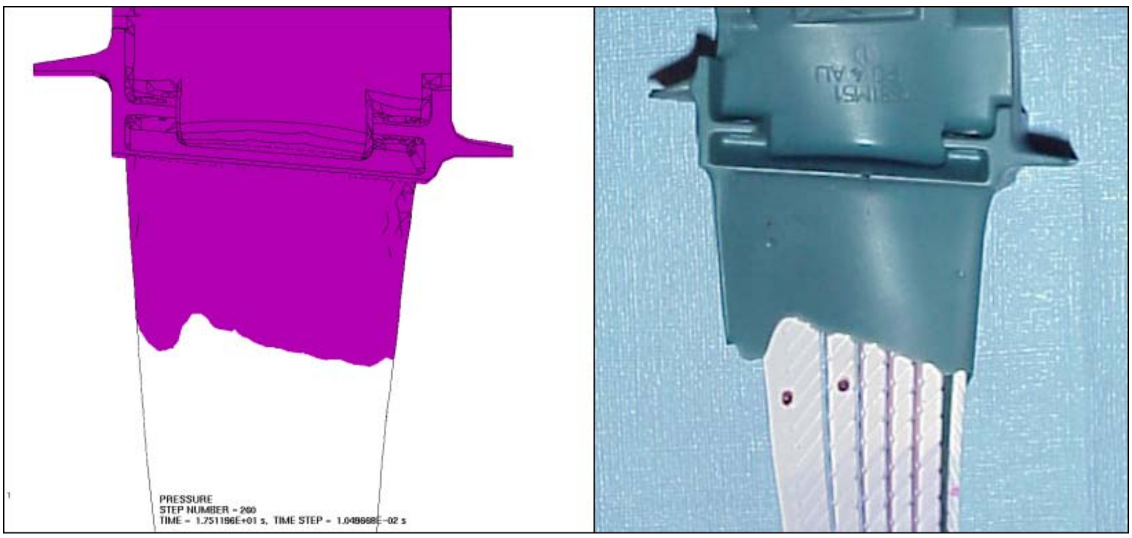

Figure 9: Wax injection modelling.

Figure 10 shows an accurate prediction and validation of the formation of knit lines in the model. This defect in the wax pattern directly produces an imperfection in the casting, creating a defective part. Figure 11 shows the ability of the computer model to predict locations of trapped air, where wax material may not be able to fill the proper cavity shape.

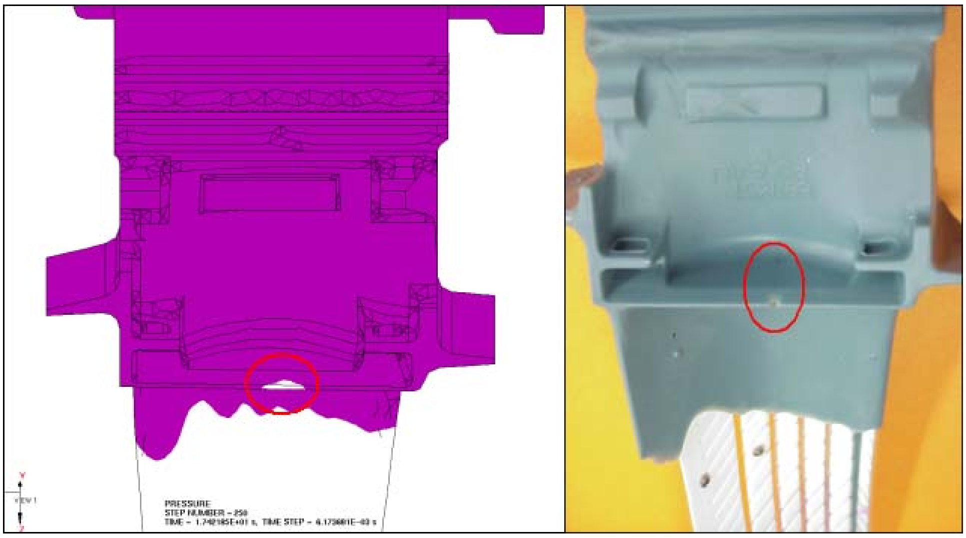

Figure 10: Prediction of knit lines.

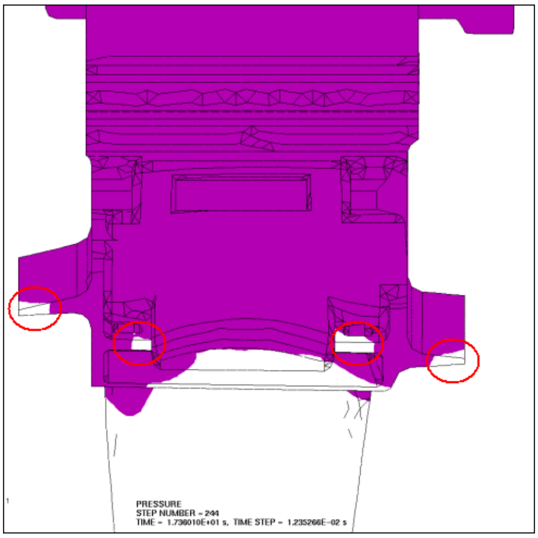

Figure 11: Potential trapped air locations.

Computer simulation of the wax injection process gives a good insight to design changes that may be required to achieve a good part. The operator can make quick gating design modifications that can lead to elimination of defects in production.

Conclusion

Advanced casting simulation tools like *Procast*™ allow the foundry engineer to quickly bridge the gap between design and manufacturing. Optimisation or improved efficiency during the manufacturing cycle leads to substantial time and cost savings. Computer analysis provides the means for verifying design ideas and viewing the effects of “what ifs” at minimal costs by avoiding time-consuming and expensive rework and retooling.