Numerical investigation on solidification in casting using ProCAST

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Abstract. This work deals with elimination of defects in aluminium alloy castings produced by gravity sand casting process. The main intention of the work is to investigate the defects and improve quality of a gravity sand cast component using Computer Aided Casting Simulation Software. In this study aluminium alloy gravity sand casting solidification has been selected as a subject of study. The mould filling process and solidification were simulated for detection of casting defects and hence optimization of the casting process. The major defects in the components are identified to be solidification shrinkage porosity defects. ProCAST simulation software is used for simulating the solidification process of casting and visualizing outputs showing possible problematic areas or defects which may occur in the cast product.

Keywords. Gravity sand casting, quality, solidification shrinkage porosity, ProCAST

1. Introduction

Virtual simulations of castings have now advanced after years of development of casting simulation programs. New techniques have emerged and research is going on to test these simulation results experimentally. Some of the related works are acknowledged here. Ravi [1] discussed AutoCAST, an intelligent assistant for casting engineers. He highlighted how it can facilitate designing, modelling, simulation, analysis and improvement of the casting products. The software also has the ability to automate the whole of the casting process, thereby allowing the user to have ultimate control over all decisions. Prabhu et al. [2] investigated the heat transfer at the casting or chill interface for the solidification of cast iron in ceramic cylindrical moulds with sand block and chill at the base. The interfacial heat flux transients and heat transfer coefficients were determined by an inverse method of solving the one-dimensional Fourier heat conduction equation. Brown et al. [3] elaborated the benefit of visualization techniques for a complete design process of a generic automotive component. They redesigned the component taking into account the design related problems involving both stress and solidification. MAVISFLOW was used for the simulation of filling and solidification. Maleab [4] demonstrated the use of CFD as a design tool for mould casting of a steel cast of an “ice cleat”. The solidification process was modelled using FLUENT and on its results, an optimum feeder placement was selected. Vijayaram et al. [5] discussed about the simulation process of casting solidification which can help the foundry engineers to optimize design parameters, apprehend the temperature history of the casting solidifications and identify the hot spot regions from the time – temperature contours.

2. Methodology

2.1. Mathematical Modeling

The continuity equation, momentum conservation equation and energy equation governs the casting solidification process.

2.2. Finite Element Analysis Procedure Using ProCAST

The common FEM analysis procedure consists of the following steps:
2.2.1 Creating 3D model
The gating and risering system was designed for the casting model and created in Solidworks 2014. Fig. 1 represents the front, side and isometric view of the casting from the left.

![Image of 3D model representing cores, gating system and risering system.]

Figure. 1 Model representing cores, gating system and risering system

This 3D model was then imported to ProCAST. The mould was developed in ProCAST by creating a solid box around the model. Fig. 2 represents the 2D representation of the mould developed.

![Image of 2D representation of the mould.]

Figure. 2 2D representation of the mould

2.2.2. Meshing
Two stage meshing was done: surface mesh and volume mesh. For surface meshing auto mesh was used. The element size for the casting, sprue, riser and the mould surface was chosen as 5, 10, 10 and 20 respectively. The entire volume was also meshed using auto mesh. 188102D and 254985 3D elements were generated. Fig. 3 and fig. 4 represents the surface and volume mesh respectively.
2.2.3. Precast
In this step, the process alloy and analysis to be done are defined. The different volumes involved are assigned as alloys, mould, chills or the core. The materials to be used for the volumes are also set. Further the thermal and flow boundary conditions are defined which includes specifying the inlet velocity, inlet area, heat transfer conditions and the initial temperatures of different volumes.

2.2.4. Running the Simulation
The simulation parameters such as flow parameters, cycles, etc. are set before running the simulation. The stop criterion is also defined. In the current study, the simulation stops when the final temperature reached in all volumes is 538°C.

2.2.5. Results and Discussions
In an attempt to minimize the casting defects and optimize the casting process 13 different designs were created and simulations were performed. Each design was for the same casting with a different gating and risering system. The inlet velocity was also varied for some designs. Use of chills in some designs distinguished them from the others. The results of 4 such simulations have been presented and discussed here.

**Design 1**
In this design the casting was horizontally placed in the mould cavity. In Fig 5 the riser is positioned at the centre of the casting. The riser dimensions were chosen by trial and error in an attempt to prevent the riser from emptying before the casting solidifies completely. The sprue height was dependent on the riser height such that both had their openings on the top face of the mould. No chills were used in this case.
Figure 6 represents runner design. The shape was chosen to promote back flow of the melt and to reduce the turbulence when it enters the mould cavity. A high inlet velocity when the melt enters the mould cavity can cause erosion of the mould sand and hence can lead to inclusion design.

**Solidification Time**

Figure 7 represents the solidification time for different portions of the casting. It is desired that the riser must solidify after the complete solidification of the casting. But in figure 7 it is observed that the riser and a few portions of the casting solidify almost at the same time. It doesn’t allow the melt in the riser to reoccupy the voids or porosities produced in the casting on solidification. Hence in this case the chances of shrinkage porosity are very high.

**Shrinkage Porosity**

Figure 8 represents the shrinkage porosity in design 1. The total shrinkage porosity in the region varied from 83% to around 20%. Figure 9 represents the occurrence of shrinkage porosity in the casting with respect to percentage solidification. Three nodes in the region where shrinkage porosity occurred were selected to plot the curve.
DESIGN 2
This design was similar to design 1. Here the riser dimensions were changed and copper chills were placed at the casting mould interface as shown in figure 10.
**Shrinkage Porosity**

Figure 12 represents the shrinkage porosity in design 3. Here also total shrinkage porosity in the region varied from 75% to around 20%. The actual location where porosity occurs is similar to that of design 2. But if we consider the position relative to the riser, then the trend is similar to design 1. In this case also the results are not satisfactory. Figure 13 represents the occurrence of shrinkage porosity in the casting with respect to percentage solidification. Three nodes in the region where shrinkage porosity occurred were selected to plot the curve.

**Figure. 11 Solidification time for design 2**

![ProCAST](image1.png)

**Figure. 12 Shrinkage porosity in design 2**

![ProCAST](image2.png)

**Figure. 13 Shrinkage porosity v/s percentage solidification**

![ProCAST](image3.png)
DESIGN 3
This design was completely different from design 1 and 2. In this design, as shown in figure 14, the casting was vertically placed in the mould cavity. The runner shape differed from that of design 1 and 2. Also, the riser was not given any draft. No chills were used in this case.

![Design 3 Diagram](image)

Figure 14 Design 3

Solidification Time
Figure 15 represents the solidification time for different portions of the casting. It is observed that the riser and only a few portions of the casting solidify at the same time. The results here are better (more preferable) than that of designs 1 and 2. From figure 15, directional solidification can be observed.

![Solidification Time](image)

Figure 15 Solidification time for design 3

Shrinkage Porosity
Figure 16 represents the shrinkage porosity in design 3. Here also total shrinkage porosity in the region varied from 75% to around 20%. The actual location where porosity occurs is similar to that of design 2. But if we consider the position relative to the riser, then the trend is similar to design 1. In this case also the results are not satisfactory.

Figure 17 represents the occurrence of shrinkage porosity in the casting with respect to percentage solidification. Three nodes in the region where shrinkage porosity occurred were selected to plot the curve.
DESIGN 4
This design was similar to design 3. Here the riser height was increased and copper chills were placed at the casting mould interface as shown in figure 18.
**Solidification Time**

Figure 19 represents the solidification time for different portions of the casting. It can be clearly seen that the riser solidifies at last. This allows the riser to provide the excess melt to the mould cavity when the casting undergoes solidification and shrinkage occurs.

![Figure 19 Solidification time for design 4](image)

**Shrinkage Porosity**

Figure 20 represents the shrinkage porosity in design 4. The total shrinkage porosity in the casting was negligible and can be permitted. The shrinkage porosity observed, was in the riser and the sprue. These parts will be removed from the casting and hence will not affect the cast quality. The results for this simulation were satisfactory.

Figure 21 represents the occurrence of shrinkage porosity in the casting with respect to percentage solidification. Three nodes in the region where shrinkage porosity occurred were selected to plot the curve. Node 1415 was located in the riser.

![Figure 20 Shrinkage porosity in design 4](image)
3. Conclusion

It is concluded that the casting simulation technology can be used as a powerful tool to predict the location of defects and eliminate them by visualizing mould filling, solidification and cooling. It can be used to identify the cause for defects like shrinkage porosity which helps to design the components effectively. It helps in trouble shooting the existing castings or developing a new casting without shop-floor trials. It not only uses fewer resources but also reduces cost and time. Modifications in riser and gating system design by changing dimensions and geometry, eliminates the shrinkage porosity defects from the cast part. Simulations show that shrinkage porosity mostly occurs in the thick portions of the casting. If the shrinkage porosity still prevails after modifications in the riser and gating system, chills can be used to promote directional solidification and eliminate shrinkage porosity. The shrinkage porosity in the casting is higher when it is placed horizontally in the mould. Thus it can be concluded that the order in which mould filling occurs, affects the quality of the casting produced.

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