

# A Review Paper on Simulation of solidification process in casting and optimization of Riser

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## ABSTRACT

*Casting solidification is actually the transformation of liquid phase to solid phase with the liberation of latent heat of fusion. During this metallurgical process, it induces casting defects like shrinkage, porosity and hot tears. To eradicate and eliminate these problems, accurate casting design and proper design of gating system is necessary. This can be predicted and designed by means of computer simulation of casting solidification. This review paper discusses about the simulation process of casting solidification, better understand the temperature history of the solidifying casting and hence to identify the hot spot region with the aid of obtained time-temperature contours. A technique to determine the thermal boundary conditions existing during the solidification of metallic alloys in the investment casting process is presented. Quantitative information about these conditions is needed so that numerical models of heat transfer in this process produce accurate results. In particular, the variation of the boundary conditions both spatially and temporally must be known. The method used involves the application of a new inverse heat conduction method to thermal data recorded during laboratory experiments of aluminum alloy solidification in investment casting shell molds. The resultant heat transfer coefficient for the alloy/mould interface is calculated. An experimental program to determine requisite mould thermal properties was also undertaken. It was observed that there is significant variation of the alloy/mould heat transfer coefficient during solidification. It was found that both melting commencement and completion were increased with increasing heating rate, in contrast inverse behavior was observed during cooling.*

**Keywords:** casting process, solidification, hot spot region, investment casting, and inverse heat conduction method.

## 1. INTRODUCTION

It is critical to the success of any metal casting process that the progress of solidification is controlled. To this end numerical modeling of heat transfer during solidification has become widespread in the foundry industry. This is because it is possible to investigate the effects of alterations to the casting variables on final casting quality, without having to do costly trial-and error experiments. Solidification heat transfer controls the evolution of macro- and micro-structural features, such as grain size and dendrite arm spacing, respectively [9]. These features, along with defects such as shrinkage porosity, determine the final mechanical properties of the casting. Commercial solidification simulation software can only produce reliable information if the appropriate material properties, and initial and boundary conditions are known accurately Metallurgical phase transformation plays a vital role in the solidification of castings [10]. Computer simulation of casting solidification of metals and alloys is a complex phenomenon [9,10]. The assumptions and constraints used for simulation are considered as a vital one [12,13]. In the casting process, the metal-mold interface will have an air gap which affects the dissipation of heat flow from the casting to the mold [12, 14]. But the application of pressure during the solidification process reduces the air gap and forms a tight contact between the casting and the mold [15, 16]. This condition releases the heat at a faster rate and produces fine grain structured castings [17].

## 2. LITERATURE

T.R. Vijayaram et. al [1] in their paper, discusses the importance of heat transfer in the simulation process is presented. This paper reviews the details of computer simulation of solidification of castings in metallurgical engineering foundries. Since, computers became widely available in industry, researchers have been working on the development of programs to simulate the solidification of castings.

Hassan Jafari et. al [2] carried out computer-aided thermal analysis to precisely measure the thermal characteristics of AZ91D magnesium alloy granules during in situ melting and solidification in investment casting process. Ceramic shell moulds of two different thicknesses equipped with highly sensitive thermocouples at three different locations were prepared to provide a range of heating and cooling rates during in situ melting and solidification. The results revealed that dissimilar thermal regimes were experienced by the granules at different locations of the mould during heating, which led to asynchronous melting of the granules. It was found that both melting commencement and completion were

increased with increasing heating rate; in contrast inverse behavior was observed during cooling. The onset and the end of solidification temperatures and duration decreased with increasing cooling and solidification rates. The information from this approach is very crucial for suppressing mould-metal reaction especially during cooling in casting of magnesium alloys by investment casting process.

Denis O'Mahoney, David J. Browne [3] presented a technique to determine the thermal boundary conditions existing during the solidification of metallic alloys in the investment casting process. Quantitative information about these conditions is needed so that numerical models of heat transfer in this process produce accurate results. In particular, the variation of the boundary conditions both spatially and temporally must be known. The method used involves the application of a new inverse heat conduction method to thermal data recorded during laboratory experiments of aluminium alloy solidification in investment casting shell moulds. The resultant heat transfer coefficient for the alloy/mould interface is calculated. An experimental programme to determine requisite mould thermal properties was also undertaken. It was observed that there is significant variation of the alloy/mould heat transfer coefficient during solidification. It is found to be highly dependent on the alloy type and on the vertical position below the initial free surface of the liquid metal. The aluminium casting alloys used in this study were 413, A356, 319 (Aluminum Association designations), and commercially pure aluminium. These alloys have significantly different freezing ranges. In particular, it was found that alloys with a high freezing range solidify with rates of heat transfer to the mould which are very sensitive to metal static head.

A. Venkatesan[4] in his study developed, a program for finite element modeling of casting solidification. The salient features of the program are: facility to incorporate latent heat through enthalpy method, incorporation of air gap by coincident node technique, ability to handle non-linear transient heat conduction through temperature dependent material properties, and object oriented programming. The code was written in C++ language and Gaussian elimination method was used to solve the matrices. This program can handle two-dimensional solidification of pure metals and alloys. Using this program, solidification of infinite slab of water was simulated and the results were compared with the reported literature and ANSYS and were found to be in good agreement. Also, solidification of Al-6 wt.% Si alloy in sand and metal mould was simulated and compared with the experimental findings and simulation results reported in the literature and ANSYS. For a given geometric profile, the solidification time obtained from the present program was 1200 s as against the literature of 1100 s and ANSYS package of 900 s. So it was found to be in good agreement with the research and experimental findings. The program was limited to 2D heat transfer analysis using linear quadrilateral elements. The program could be extended for predicting the grain structure. From the simulation results, the solid-liquid interface velocity (R) and solidification rate (dT/dt) could be calculated and using these values thermal gradient (G) could be found and there by the most probable grain structure could be predicted.

M. Ruhul Amina and Anurag Mahajan[5] successfully implemented Prandtl mixing length theory with average heat capacity to model turbulent continuous casting (CC) process. This method features the simplicity of zero equation model along with ease of maintaining higher time step increment using average heat capacity method. A series of simulations were investigated to study the effect of inlet speed (Pe), superheat ( $\Theta_0$ ), mold cooling rate (Bim) and post mold cooling rate (Bip) on the process characteristics and were presented in terms of viscosity contours, location and slope of the solidification front, axial velocity profiles, velocity vectors, local heat flux and shell thickness. The ranges of the parameters studied in the current work were: Pe = 3.5–6.1,  $\Theta_0$  = 1.2–2.0, Bim = 0.2–0.4 and Bip = 0.1–0.4. The effect of mold length (Lm) was also investigated to establish remedies of breakout due to higher Pe and  $\Theta_0$ . The current studies reveal that Pe,  $\Theta_0$  and Lm have significant effect on the performance and productivity of the cast material.

Lei Zhang et.al[6] in their paper studied, a mesh-less method, finite point method, and applied to model metal solidification processes in continuous casting. An additional term is added to stabilize the computation with Neumann boundary. The enthalpy method is used to calculate the latent heat and the corresponding iterative solution is given. An iteration scheme for nonlinear material calculation is also constructed. The model is verified by the classical Stefan problem and a 2D FEM solidification example. And then it is applied to the simulation of the solid shell growth in the continuous casting of a large square blank in mold. The result is coincided with the measurement.

Jinwu Kang et.al[7] proposed a new method – post solidification intensive riser cooling (PSIRC). Risers are cooled by forced air or water mist from its top surface as the solidification of a casting finishes, then the risers are turned into cooling passages during the cooling process of a casting with contrast to their function of feeding passages during the solidification process. This method can realize inside-out, fast and even cooling of castings, which may improve the production efficiency and reduce residual stress and deformation. A forced air cooling system with close-loop control for PSIRC was designed and developed. The temperature difference between the typical thick and thin locations of a casting was fed back to control the cooling intensity. The PSIRC method was applied to the casting process of a stress frame specimen and a hydro turbine blade. The effect of PSIRC on the cooling of the castings was investigated. The cooling speed of these castings increased apparently with improved temperature distribution uniformity. One day was saved for the blade casting before shakeout. The PSIRC method improved the strength and hardness of the blade casting, and significantly reduced its residual stress meanwhile.

Pavan Kumar Penumakala et.al[8] presented a semi-analytical model to find the solidification length of continuously cast metals. An existing theoretical solution for solidification in an infinite slab, which is maintained at constant

surface temperature, is extended to a finite slab. For the case of a finite slab, the governing 2-D heat conduction equation is solved in the non-dimensional form using a constant surface temperature as a boundary condition. The solution also delivers the guidelines for the kind of cooling profile which has to be applied in reality. It is found that the total solidification length (metallurgical length) in a continuous casting process is proportional to the mass flow rate and specific heat capacity and inversely proportional to the conductivity and width to thickness ratio of the slab. The novelty of this study is that it provides design guidelines for the process engineers to find the solidification length beforehand for a given cast alloy and ingot geometry.

### **3. CONCLUSION**

By using thermal analysis approach the behavior of the metal during melting and solidification could be determined. It was found that melting behavior of the granules depends on the locations inside the ceramic shell investment casting mould. The results revealed that the transition temperatures were influenced by cooling or heating rates. Increasing heating as well as melting rates increased the melting initiation and completion to higher degree, respectively. Casting solidification simulation process is used to identify the defective locations in the castings from the generated time-temperature contours. It is concluded that casting solidification simulation technology is used to eliminate defects like shrinkage, porosity and to locate the hot spot regions which helps to design the components effectively. Post solidification intensive riser cooling method (PSIRC) was proposed, in which risers were cooled by forced air or water spray after the solidification of a casting, turning risers into cooling passages during the cooling process of castings in contrast to feeding passages during the solidification process. It can quicken the cooling process of the whole casting inside out, and make the cooling of the casting more uniform; finally, it may improve production efficiency and reduce residual stress and deformation.

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