Application of Computer Simulation in Metalcasting Course

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Abstract

Modern developments in computer technology and computer software have allowed simulation of very complex physical phenomena, which was almost impossible or prohibitively expensive even several years ago. One such area is fluid flow involving heat transfer and coupled with phase transformation. The problem is very difficult as it sounds, but nowadays one can obtain very good results even on a personal computer within a reasonable period of time. The manufacturing process that belongs to this group of problems is metalcasting. In the past, metalcasting was more of an art than the science; however, nowadays computer software is successfully applied to simulate filling and solidification process. The accurate result of simulation allow improved casting design along with the optimization of the gating and risering system used to produce a sound product.

Introduction

Tremendous developments in computer science, engineering and technology in recent years have brought many changes in the way we conduct our daily activities. Computer speed and memory has been increased, and continues to increase at a very fast pace, allowing us to use them for very complex and complicated applications. Computers are used for real time simulation and control of very fast dynamic systems, and computers are now commonly used to analyze very complex structures and processes. What seemed impossible, or nearly impossible some ten years ago, is a reality today, and the scope of potential applications is ever increasing, and the accuracy of computer generated solutions is constantly improving.

The computers have played and continue to play a very important role in the manufacturing processes, from the design of parts, to manufacturing production planning. They are resulting in improved products and reduced production times, which all lead to a more satisfied customer and thus in an increased competitiveness for both manufacturer as well as the end user.

Metalcasting is one of the oldest and also one of the most complex manufacturing areas. The metalcasting process has been known for over 10,000 years, and today it still has the same basic characteristics as it had when our ancestors where casting small decorative pendants and beads. However, in the meantime, metalcasting industry has evolved from purely art to a very scientific type of manufacturing process. Foundrymen have been learning on their own as well adopting knowledge from other engineering and science areas, to the point where nowadays foundrymen can control the process and predict its results to a great degree of accuracy. A significant part in the advancement of metalcasting as a science can be attributed to developments in computer science and technology. Today, a modern metalcasting facility can not realize its daily production without application of computers in nearly all segments of the metalcasting process.

Computers are applied in design of castings, from a rough idea to its functionally optimized shape. These ideas are then verified for their manufacturability, i.e. whether the part can be cast successfully or not, upon which the designer can modify the design and repeat the process. Foundrymen can fairly easily simulate filling and solidification of even most complex castings and predict potential problem areas. Changes in design and rigging are fairly easy and fast on computer, which allows inexpensive and fast "what-if" analysis and verification of an idea before committing potentially significant resources to actual pattern making and casting. Thus, allowing foundrymen to reduce cost, improve quality and increase the speed of product delivery.

Computer technology has revolutionized many aspects of manufacturing, and it has certainly contributed to the significant advancement of the metalcasting.

Geometric Description and Modeling of Solidification Heat Transfer

The very first step in computer modeling and analysis of the castings is the geometric description and discretization of the actual part. There are several reasons for unambiguous and accurate representation of the casting geometry: (1) accurate rigging design, (2) precise quotation estimate of the casting cost, (3) determining of melting and molding capacity, and (4) generating tool paths for both pattern machining and machining of the casting. There are several methods for geometric representation, and the following are the most common: (1) constructive solid geometry, (2) boundary representation, and (3) wireframe. With accurate geometry specifications obtained with one of many commercially available software packages, one can proceed with simulation of the casting process. The very first commercially available metalcasting related simulation software packages dealt with fairly simple problem of 2D casting cooling and solidification. With increasing computer power, these packages now deal with more complex 3D heat transfer problems that take into consideration conduction, convection, radiation and phase transformation related phenomena.

Modeling of Fluid Flow and Heat/Mass Transfer

Considering and modeling only heat transfer phenomena is sufficient in some instances where heat dissipation is negligible during mold filling stage of the casting process, and where metal flow is relatively laminar. However, in the case of small to medium castings with fairly thin sections, where heat dissipation is significant, the flow of metal becomes very important. The major reason is that the metal can freeze before it fills the entire mold cavity leading to misrun type of casting defect, or temperature can change so much that assumption of a uniform temperature field commonly made in the simple heat transfer analysis cannot be considered correct and thus results of corresponding simulations are quite likely invalid. In addition to heat dissipation, type of flow becomes very important in case of metals that are fairly reactive at high temperatures and which may form oxides easily along the surface if exposed to oxygen. This is a common problem when casting aluminum which oxidizes fairly easily. In the case of turbulent flow aluminum oxide can be trapped within the metal, thus reducing strength of the material.

Today's software packages can be divided into two categories according to the computational technique for modeling flow during mold filling[1]:

- Energy balance techniques based on the Bernoulli equation and the Saint-Venant equations
- Momentum balance techniques based on the Navier-Stokes equations as embodied in the Marker-and-Cell group of programs which include the Marker-and-Cell (MAC), Simplified Marker-and-Cell (SMAC), and Solution Algorithm (SOLA) techniques.

The first category is very useful for analyzing flow in the gating system, i.e. sprue, runners and gates. It gives fairly accurate results with minimum computational time. The example of such software package is AFS Gating System[2]. However, filling of the mold cavity requires a more sophisticated technique which belongs to the second category. These techniques differ mainly in the way they keep track of the location of the free surface and somewhat in the way they perform some of the internal iterations. In general they are based on the same principles and on the finite difference scheme for solving partial differential equations for continuity, momentum and free surface stress equilibrium, for the enmeshed representation of the analyzed physical domain. There are a number of different commercially available software packages that are being successfully used for simulation of fluid flow and heat/mass transfer in metalcasting, e.g. Flow-3D, AFSolid, ProCAST, Magma. A number of software developers have also performed correlation between numerical simulation and actual casting results, and their results look very impressive taking into consideration complexity of the involved physical phenomena and limited data base on physical properties required for accurate numerical analysis.

Modeling of Microstructural Evolution

In the recent years significant efforts have been made toward modeling and simulation of microstructural evolution in castings. The first attempts were made in applying analytical methods to eutectic gray, ductile, and white iron[3], and then they were extended to hypoeutectic irons and to eutectoid transformations[4]. The goal is to analytically correlate grain morphology with the cooling rate of the casting, and hence predict mechanical properties of the casting. These attempts are still in their infancy, but the efforts in this area will have significant impact on casting design and modeling as well as on prediction of the casting quality.

Conclusion

Computer simulation can be a very important tool in process and product design for improved manufacturability, and in this specific case castability. There are a number of issues related to accuracy of numerical simulation that still remain to be solved and/or improved, but even presently computers are of tremendous help to designers in reducing product design time and manufacturing costs.

References

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