Application and development of numerical simulation technology in Casting

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Abstract: The basic theory of the numerical simulation of casting and casting process, also the development and application of numerical calculations in the foundry engineering. Outlined the main feature of the softwares of numerical simulation of casting both here and abroad , analyzes the softwares played a significant role in actual casting and research, meanwhile pointed out the problems and development direction of the casting simulation softwares. Description reasonable use of simulation software can improve the quality of castings, Optimize the casting process, shorten the duration of the casting design and reduce costs.

Key words: casting; numerical simulation; casting simulation softwares; castings; Optimization of casting

I.   Introduction

Casting is a liquid metal material forming process. The liquid metal which through smelting and necessary processing of blast furnace, pouring into the corresponding mold, solidified and cooling ,the   process called casting[1-3]. Also requares the multi-channel post-treatment processes after casting molding, such as shakeout, cleaning, finishing, heat treatment and coating necessary, to get to meet the requirements of the finished castings[4-7].

Before the production of casting. Documentsof scientific and technical should be developed to control the casting production process. This is the casting process design. The process is based on the requirements of the casting, Production volume and production conditions, and structural analysis of the castings.Establish a scheme of the casting process[8-9]. Process parameters and process planning. Preparing   the processing card, the whole process of design process equipment. Therefore, the quality of Casting process design, Has great influence on the casting quality, productivity and cost.In the past, Casting process design is largely based on the experience. Unable to meet the competition requires of high quality and short delivery in castings market. for this purpose, Foundry workers need to find scientific, fast, and reliable means of casting process design, in order to satisfy the requirements of modern industry for foundry industry. Numerical simulation of casting process is the important technology to reflect the design method[10-11]. Before actual production may carry on the computer numerical simulation of casting production, predict the possible defects, and further improve the process and structure, to optimize the casting process, to eliminate the casting defects, improve product quality, process quality comparison of different implementation process optimiz ation. And because the simulation is conducted on computer.Without the actual production. can save a lot of manpower, material resources and financial resources. According to the American academy of engineering and technical measure of the committee[12-13]. Simulation can improve the quality of products 5 times to 15 times, Increasing the rate of material production by 25%, To reduce the cost of Engineering Technology in 13% ~ 30%, Reduce labor costs by 5% to 20%. Improving the input equipment utilization rate 30% ~ 60%. Shorten the product design and trial production period of 30% ~60%.

II.   The basic theory of numerical simulation of the casting process

Numerical simulation system of the casting process based on casting filling and solidification process as the research object, using numerical analysis techniques, database technology and visualization technology, computing and display casting molding process of the flow field, temperature field and stress field distribution, and the simulation results predict casting quality, thereby improving the casting process.

2.1   Numerical simulation of mold filling, solidification casting system

Numerical simulation system of mold filling、solidification includes three modules, there are pre-processing software, intermediate calculation software and post-processing software. As shown in Figure 1, the main function of pretreatment software module is to realize the geometric conditions of loading, parameter setting, meshing and provides informationabout casting process.The task of intermediate calculation software module is based on the physical field which casting process involves, provides a computational model for numerical calculation, and the prediction of the casting quality according to the relationship between the quality of casting or defects and physical field.The main contents include the temperature field、 flow field、 concentration field、 stress field and relates to the microstructure calculation of grain nucleation growth. The casting process of macro simulation software has been used to guide the practical production, microstructure simulation has also made some breakthrough progress. The task of post-processing software module is displaying the module calculation results of filling and solidification process in a form of intuitive graphical.Let us can directly observe the simulation results.
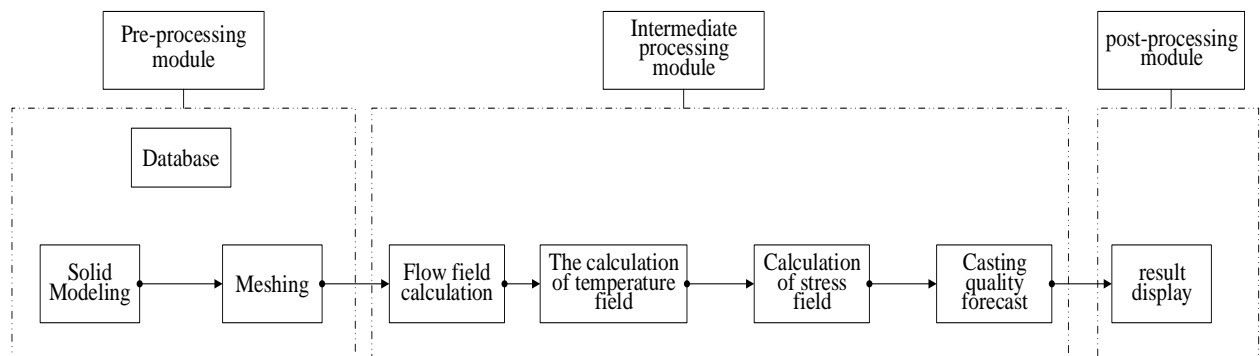

Fig.1 The composition of casting process simulation system

2.2   The main methods of numerical simulation of casting process

Research on the phenomenon of fluid transport in general, there are two ways: one is continuous macroscopic theories include fluid mechanics and thermodynamics; the other is a microscopic theory of kinematics.Both methods can deduce the same system equations. In the process of numerical simulation, although the discrete solutions methods used by different, but they all have the same characteristics. First, the calculation region is divided into a number of the control body or grid, and discretize differential equations into algebraic equations on these small pieces.

The method of discrete on flow problems are mainly have the Finite Element Method、 Finite Difference Method、Finite Volume Method、Boundary Element Method、and Lattice Gas Method.The lattice gas method is developed in recent years a new method of computational fluid dynamics, the basic idea is to use a simple local interactions to represent the overall behavior and evolution of complex systems. According to the description of the motion of fluid molecules, make the cellular automata concrete then get the simulation of fluid mechanics of lattice gas automata. Numerical simulation of casting process, high-temperature liquid of metal flow can be regarded as incompressible viscous Newtonian fluid unsteady flow. Method for treatment of the free surface are

mainly the MAC method、VOF method and conserved scalar equation method. By solving the mass conservation equations of fluid motion、Momentum conservation equation、Energy conservation equation and Volume function equation. At the same time record the change of the fluid surface, get the liquid metal filling liquid. So as to optimize the mold design, predict casting defects such purposes.

1. Mass conservation equations

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \tag{1}$$

2. Momentum conservation equation - (N-S equation)

$$\rho\left(\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}\right) = -\frac{\partial p}{\partial x} + \rho\, g_x + u\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right)$$

$$\rho\left(\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z}\right) = -\frac{\partial p}{\partial y} + \rho\, g_y + u\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right)$$

$$\rho\left(\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z}\right) = -\frac{\partial p}{\partial z} + \rho\, g_z + u\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right) \tag{2}$$

3. Energy conservation equation

$$\frac{\partial(\rho c_p T)}{\partial t} + \frac{\partial(\rho c_p T u)}{\partial x} + \frac{\partial(\rho c_p T v)}{\partial y} + \frac{\partial(\rho c_p T w)}{\partial z} = \frac{\partial}{\partial x}\left(\lambda\frac{\partial T}{\partial X}\right) + \frac{\partial}{\partial y}\left(\lambda\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(\lambda\frac{\partial T}{\partial z}\right) \tag{3}$$

4. The volume of the functional equation

$$\frac{\partial F}{\partial t} + u\frac{\partial F}{\partial x} + v\frac{\partial F}{\partial y} + w\frac{\partial F}{\partial z} = 0 \tag{4}$$

where ρ is density of the fluid; V is the flow rate of the fluid; Component of its x, y, z directions are u, v, w; t is the time; P is the pressure per unit density; u is the kinematic viscosity of liquid metal; g_x、g_y、g_z are the acceleration of gravity along the X, Y, Z direction. c_p is the liquid metal heat capacity at constant pressure; T is the temperature; F is the volume function, $0 \leq F \leq 1$. For the above equations, first, discrete processing, and then adopting SOLA method to solve stress field, velocity field. Using VOF method to deal with free surface and get the solution.

III. Introduction the main casting process simulation software

In recent decades, with the constant improvement of the numerical simulation technology on casting mold filling, solidification process. Commercial software for the analysis of the casting forming process are also emerging. The first software in this respect is in 1989 by the German Aachen University Sahm P. Professor R presided over the development of MAGMA Soft, and then a lot of commercial software continues to emerge. At present, many countries have their own commercial simulation software, such as the United States AFS Solidification System, Flow3D and ProCAST, France's SIMULOR, Finland CASTCAE, the Swedish NOVAFLOW&SOLID, British SOLSTAR, Japan ADSTEFAN, Belgium Sirris Institute ViewCAST, South Korea's Any Casting and China FT-star. The software has been integrated with the actual production, and access to the more widely used in developed countries casting enterprises, and achieved good economic benefit.

Table 1 main domestic and foreign casting simulation software

Software Name	Country	Algorithm	Analysis of content
MAGMASoft	Germany	FDM/FEM	Flow and heat transfer, stress, microstructure
Flow3D	USA	FDM/FVM	Flow and heat transfer
ProCAST	USA	FEM	Flow and heat transfer, stress, electromagnetic casting
SIMULOR	France	FVM	Flow and Heat Transfer
CASTCAE	Finland	FDM/CVM	Flow and heat transfer, microstructure
NOVAFLOW& SOLID	Sweden	FDM/Modulus Method	Flow and Heat Transfer
Any Casting	Korea	FEM	Flow and heat transfer and stress
FT-Star	China	FDM	Flow filling process, cooling and solidification process, charge-coupled heat exchanger process

IV. Progress of numerical simulation software in real research

With the development of Casting numerical simulation software, its function gradually improved. Resulting in research on such practical problems, also become increasingly dependent on the aid of simulation software. Effect is significant for the research results.

4.1 The application of FLOW3D numerical simulation software

Flow-3D was developed by the US company Flow Science three-dimensional computational fluid dynamics and heat transfer analysis software, formally withdraw from 1985. The CFD settlement technology of True V.O.F in the practical problem of simulation and the accuracy of the calculation is by users praise and commendation. Its FAVOR skills but also for Free surface, such as the common Metal Casting、Earth Water Conservancyand other complex issues provides a more accurate, more efficient answers. The characteristics of highly functional, easy to use and strong engineering application.Gradually in CFD and heat transfer areas to be more widely used. Flow-3D software now has been widely used in metal casting industry. Flow-3D uses a unique method TruVOF for calculating, which is the result of further improvement of the VOF technique, can accurately track changes in the free surface. So it can accurately simulate flow problems with a free interface, accurately calculate the dynamic free surface boundary flow aggregation and splash, especially for numerical simulation of high-speed high-frequency flow state.Flow-3D's "Non-Inertial Frame" "General Moving Object" computing model. Changes in the liquid level of freefall or rotational movement of the fluid around the area on the object can be accurately simulate, and the changes of the internal surface of rotational movement or the freefall of flow area.

4.2 The application of MAGMASOFT numerical simulation software

MAGMASOFT casting simulation software for casting professional staff to improve the quality of castings, reduce costs, and providing a powerful tool for the optimization of process parameters. Many factors influence the quality of casting, and quality assurance must rely on the correct casting process. MAGMASOFT is designed to support from the smelting metallurgy, modeling and mold making, casting process until the heat treatment, furnace materials and repair, overall and comprehensive process optimization tool. MAGMASOFT is suitable for casting production of all casting alloy materials, ranging from gray iron casting, aluminum alloy sand casting, to large steel casting. MAGMASOFT more for different casting process design special modules, it uses physical behavior simulation of heat transfer and fluid. Solidification process of stress and strain, microstructure formation, can accurately predict casting defects and improve the efficiency of existing processes, improve casting quality. The simulation of mold filling, solidification, mechanical properties, residual stress and distortion, etc. for the comprehensive optimization of Foundry Engineering provides the most reliable guarantee.

4.3 ANYCASTING numerical simulation software applications

Truly based on the Windows platform, easy to use advanced solver model, fast calculation speed, can make a decision within one working day for filling and solidification defects prediction model and criterion, parameters easy setup and interfacial heat transfer coefficient is automatically set, simulating a variety of casting process filling, solidification, heat conduction and the whole process, can accurately predict the porosity, shrinkage shrinkage, cold shuts, slag, deformation and other defects. Guidance riser, cooling system design and optimization of the casting mold design process parameters to reduce the number of product tryout, improve product quality, reduce the casting cost and improve the market competitiveness.

V.   Conclusions

In recent years, with the continuous improvement of casting process numerical simulation techniques, the commercialization softwares are also emerging which to analyze the formation process of casting. But there are many aspects of these software systems need further improvement, such as computational efficiency and accuracy as the software for practical engineering application is very important, it should be further improved. 1. Simulation of Filling Process. 2. Simulation of the solidification process. 3. Accurate measurement of thermal physical parameters. 4. Many current calculation results due to the lack of effective observation instruments and difficult to verify, therefore, need to develop appropriate price and the observation equipment on effective flow process. 5. Develop the intelligent model of casting process design. The simulation of casting process services for casting technology finally. If we can develop thetechnics design automation software based on casting. Will significantly increase the usefulness of the simulation software.

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