PROCESS SIMULATION OF DIE CASTING

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1. PREAMBLE

Die-casting is a 'near net shape' manufacturing process extensively used for producing quality products for many engineering applications. Die casting has the ability to produce the castings with thin walls, low weight, high integrity, close dimensional control, good surface finish, good strength and high rate of production than any other casting process. The die casting method is especially suited for applications where large quantities of small to medium sized part is needed with good detail, a fine surface quality and dimensional consistency. Most die castings are made from non-ferrous metals, specifically zinc, copper, aluminum, magnesium, lead, and tin based alloys, although ferrous metal die castings are possible. There is always a challenge to design and manufacture new products with high quality and shorter lead time at faster production rates. Figure 1 shows die-casting process schematically along with terminology.

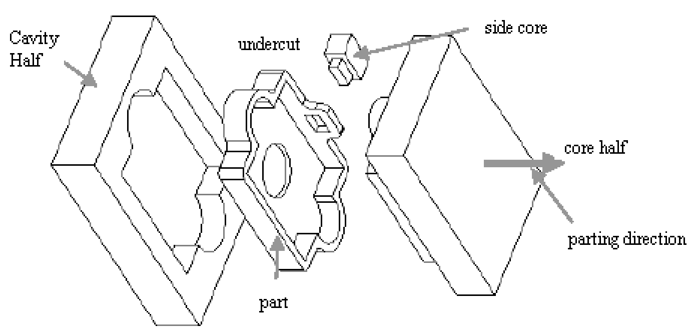


Figure 1: Die-casting process terminology

2. PHASES OF DIE CASTING PROCESS

There are five major phases in the pressure die casting process. These phases of die casting process are discussed below.

Phase I: Pouring of molten metal- The molten metal is poured into the die under pressure. The smoothness of the flow of the molten metal in the mould cavity depends on the effectiveness of the pouring system which in turn depends on accurate positioning and orientation of the gates, runners and risers.

Phase II: Mould cavity filling- Mould filling takes place while pouring the molten metal through the runner and gate. The pressure, temperature and speed of the molten metal needed to be considered while simulating the mould filling process.

Phase III: Solidification of the molten metal- The rate of solidification and cavity shape must be controlled for die casting to minimize the casting defects. The shrinkage and draft allowances are also considered.

Phase IV: Ejection of the casting: Proper location and orientation of the ejector mechanism is essential for efficient removal of the part out of the die, after the solidification of the molten metal

Phase V: Closing of the die cavity: Finally, the mold is sprayed with lubricant and closed for the next cycle. The lubricant sprayed helps to control the temperature of the die and assists in the removal of the casting.

3. LITERATURE REVIEW

Researcher had done vibrant research in the field of process simulation of die casting process. Some research papers by key researchers in the field of process simulation of the die casting have been discussed in the next section.

Author(s)	*Method Adopted*	*Issues Addressed*	*Remarks*
Shepel, Paolucci (2009)	Volume of fluid method (FEM based)	Filling and solidification of die casting of automotive piston head	Material properties and boundary conditions imposition to be improved
Cleary, Ha, Parkash, Nugyen (2010)	SPH, MAGMAsoft simulation	Filling of Die Cavity of Automotive Parts	SPH results are close to the experimental results than MAGMAsoft
Yan (2011)	FEM based Numerical simulation	Filling process in die casting	Temperature in solidification process, shrinkage and slack were predicted, casting defects are reduced largely
Ha, Cleary, Parkash,	SPH, MAGMAsoft & experimental	High pressure die casting process simulated of	SPH simulated fine details of flow better than MAGMAsoft

Alguine, Nugyen, (2009)	simulation	automobile piston head	especially at sharp corners and through thin sections.
Kulasegaram, Bonet, Lewis (2009)	Corrected Smooth Particle Hydrodynamics	Mould Filling in Die Casting	Validated the CSPH results with experimented results and proved these results slightly better.
Sulaiman, Hamouda, Abedin, Osman (2011)	Network element method	Mould filling	pressure velocity, temperature & draft angle are studied
Ha, Cleary, Parkash, Nugyen (2010)	SPH, MAGMAsoft simulation	Filling in Gravity Die Casting	SPH simulates free surface behavior and fine details of flow better than MAGMAsoft

4. SIMULATION

Certain advantages of using simulation are discussed below.

- Model a real-life or hypothetical situation on computer to reveal system working
- Predictions of behavior of system by changing variables
- Tool to create virtual environment of the real time system
- The formal modeling of systems via mathematical model
- Analytical solutions enabling the prediction of the behavior of the system from a set of parameters and initial conditions
- Several software packages (Monte carlo simulation stochastic modeling, multi-method modeling

5. METHODS FOR PROCESS SIMULATION OF DIE CASTING

The process simulation of the die casting can be of great help in locating various defects in the die casting process. The simplification of the design process forms the basis for more efficient simulation of the die casting process. Certain issues related to reduction of the tooling cost and minimizing casting defects still need to be addressed.

Hit and Trial Methods

Earlier, hit and trial methods were used for simulation of pressure die casting process. These methods were based on analyzing the sample die casting process according to certain expert guidelines, suggesting some suitable modification in the design or in the process variables. But this process was very time consuming and prone to human errors. With the recent development of free-surface tracking algorithms for finite element flow solvers, use of FEM meshes for accurate flow solving has become practical. With the advent of finite element based method (FEM), the prediction of the defects was relatively easier due to better simulation environment. The finite element methodology for process simulation of die casting is discussed in the next section.

Finite Element Methods

Finite Element Methods are well established for a number of application areas including stress analysis, heat transfer etc. The applications of FEM to the fluid flow are very recent. In FEM, the prediction of the problem was relatively easier due to better simulation environment. The behavior of the molten metal during filling the mould cavity and solidification of the part has become more efficient than earlier methods. The results of the FEM based methods are also widely accepted. Finite Difference Method, Boundary Element Method, Porous Media Method, Particle Numerical Method are amongst few finite element methods for process simulation of die casting. The model developed for process simulation analysis of die casting based finite element system generally consists of five steps as follows:

1. Conceptual Design
2. Initial Geometric (Mathematical) Model
3. Mesh Generation
4. Element Volume & Material Properties
5. Element Equations
6. Assembly of system equations
7. Boundary Condition Application
8. Solution of equations and post-processing

Conceptual design is the earliest design phase and consists of production of design specifications and construction of the initial geometric model. Current CAD systems adopt a geometric model as the product model, where only ideal geometric shapes and technological information (e.g. dimensions, tolerances and materials properties) are incorporated. Mesh generation involves splitting a network of volume over the entire domain. The element equations are generated and the system equations are assembled them by enforcing the essential boundary conditions. The solution of the system equations yields the operating parameter for the die casting process. Most commercially available solidification and mold filling analysis software packages (e.g. MAGMAsoft, ProCAST, QuickCAST, SimpoeWORKS, CastFLOW etc.) are designed on the basis of finite element technique.

Although the FEM methods are used for the process simulation of the die casting efficiently yet mesh distortion and entanglements problems limit the use of FEM methods mainly to low pressure casting. The dynamic and high pressure flows cannot be accurately simulated with FEM based methods. The finite element based methods are not able to simulate the fine details of the fluid motion; droplet formation and splashing especially at sharp bends and through thin sections. The meshfree methods, designed on the basis of element free approach, could be an alternative to the FEM based methods. The meshfree methods can be considered as an alternative to finite element methods for simulation of the die casting process. Various meshfree methods for die casting process simulation are discussed in the next section.

Meshfree Methods

The reliance on mesh in conventional finite element methods leads to many problems including mesh entanglements and mesh refinement. To ameliorate these difficulties, meshfree methods have been developed which do not require mesh to obtain the discrete equations. The approximate solution is constructed only in terms of set of nodes and description of the internal and external boundary of the surface. Major Meshfree methods are discussed below.

A. The Smoothed Particle Hydrodynamics (SPH)

The advent of the mesh free idea dates back from 1977, with Monaghan and Gingold developed a Lagrangian method based on the Kernel Estimates method to model astrophysics problems. This method, named Smoothed Particle Hydrodynamics (SPH), is a particle method based on the idea of replacing the fluid by a set of moving particles and transforming the governing partial differential equations into the kernel estimates integrals. The SPH method has been successfully applied to a wide range of problems such as free surface, impact, explosion phenomena, heat conduction etc.

B. The Diffuse Element Method (DEM)

The first mesh-free method based on the Galerkin technique was only introduced over a decade after Monaghan and Gingold first published the SPH method. Many authors state that it was only after the Diffuse Element method that the idea of a mesh-free technique began to attract the interest of the research community. The idea behind the DEM was to replace the FEM interpolation within an element by the Moving Least Square (MLS) interpolation.

C. The Element-Free Galerkin Method (EFGM)

In 1994, Belytschko and colleagues introduced the Element-Free Galerkin Method (EFG), an extended version of Nayroles's method. The Element-Free Galerkin introduced a series of improvements over the Diffuse Element Method formulation, such as

- Proper determination of approximation derivatives
- Imposing essential boundary conditions
- Process for Numerical Integration

E. Finite Point Method (FPM)

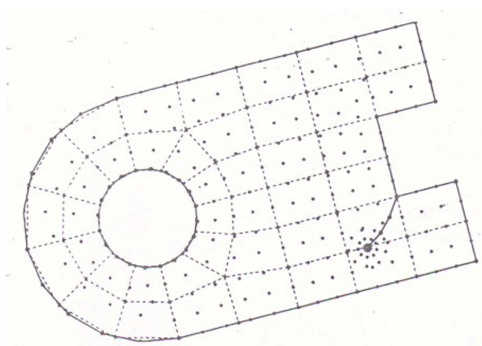
The FPM was proposed by Ongate and colleagues in 1996. It was originally introduced to model fluid flow problems and later applied to model many other mechanics problems such as elasticity and plate bending. The method is formulated using the Collocation Point technique and any of the following approximation techniques, Least Square approximation (LSQ), Weighted Least Square approximation (WLS) or Moving Least Squares (MLS) can be used to construct the trial functions.

F. Meshfree Local Petrov-Galerkin Method (MLPGM)

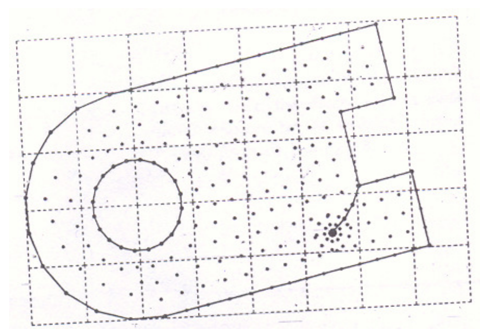
The MLPGM introduced by Belystchko presents a different approach in constructing a mesh-free method. It is based on the idea of the Local weak form which eliminates the need of the background cell and, consequently, performs the numerical integration in a meshfree sense. The MLPGM uses the Petrov-Galerkin method in an attempt to simplify the integrand of the weak form. The MLPGM and its different schemes have been applied to a wide range of problems such as Euler-Bernoulli Beam Problems, solid mechanics, vibration analysis for solids, transient heat conduction, amongst many others.

MESHFREE VERSUS FEM

In FEM, node addition in the geometry leads to change in mesh structure and corresponding element and system equation. The major advantage of meshfree methods over FEM is that any number of nodes can be added to the geometry without affecting the cell structure. This is due to the fact that the node addition in a particular cell changes the element equation of the particular cell only. Meshfree methods actually used background cell structure just similar to the mesh in FEM. The element equations are constructed for each cell structure separately and the system equations are constructed by combining the cell level equations.



(a)



(b)

Fig 2(a): FEM mesh 2(b) Meshfree Cell Structure

Fig 2(a) & Fig 2(b) shows the FEM mesh and the meshfree cell structure for crack propagation problem of a typical part. The rectangular cell structure in the meshfree method contains different number of nodes in each cell. The polynomial basis selected in the approximation function will determine the degree and continuity of the basis function and the system equations.

6. CONCLUDING REMARKS

Meshfree methods theory is still in its infancy compared with that of Finite Elements and Finite differences. Collocation point methods are said to be truly mesh-free, however, the procedure is known for its instability and low accuracy. On the other hand the Galerkin procedure is stable and more accurate but Galerkin formulation are not truly mesh-free due to the use of background cells.. From the few publications found, meshfree methods are clearly better than finite element based method due to the absence of mesh thus eliminating the problems due to mesh entanglement and mesh distortion in the approximation functions. One can verify that these methods offer advantages either on their own or coupled with FEM and more investigation is needed in order to take full advantage of these procedures.

5. REFERENCES

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