Gravity Die Casting Process
Die Design and Process Optimisation

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Abstract.

The design of dies, gating and risering system in gravity die casting or permanent mould casting by conventional approach is a difficult process and time consuming. Gravity die casting used for non-ferrous casting applications is increasingly used in the foundries today as an economically viable casting process. The conventional trial and error based die design and process development is expensive and time consuming. Such a procedure also **might lead to higher rejections and lower casting yield**. Further any changes and modifications to be incorporated to the die design, involves metal cutting and reshaping. Computer simulation procedure based process development and die design can be used for rapid process development and die design in a shorter time. Such a computer simulation based procedure, often using state of the art FINITE ELEMENT ANALYSIS based software systems, can improve the quality and enhance productivity of the enterprise by way of faster development of new product. FEM based simulation software systems help the designer to visualize the metal flow in the die cavity, the temperature variations, the solidification progress, and the evolution of defects such as shrinkage porosities, cold shuts, hot tears and so on.

Authors have applied FEM simulation to design and develop a variety of Aluminium gravity die casting processes. The components include a gear casing and a manifold. In this process different options of gating design studied by FEM simulation, and the resultant patterns of solidification are discussed.

ProCAST® a FEM simulation based virtual casting environment for analysis of casting process is used as a tool for die design and process optimization.

Introduction

Gravity die casting or permanent mould casting as the name suggests is a process wherein the liquid metal is poured into metallic moulds without application of any external pressure. The liquid metal enters the cavity by gravity. Gravity die casting (GDC) is different from High Pressure Die Casting (HPDC), where the liquid metal is injected into the metal mould under very high pressures for production of thin walled smaller castings with better dimensional accuracy and surface finish.

In the design of dies for GDC, usage of "cores" is an important issue. The undercuts and the hollow shapes are produced with the help of additional mould parts called "cores". For simple shapes without any under cuts the metallic cores could be used, whereas for undercuts and complex hollow shapes, which are difficult to retract, sand or plaster of paris cores are employed. The gravity die casting process is suitable for high volume production of non-ferrous alloy castings of Aluminium, Magnesium, Copper and Zinc base alloys and to limited extent for cast iron castings. Castings can be manufactured by operation of dies manually or by automatic devices or through die casting machines depending on the quantum of production. The die materials used are gray cast iron and steels. Typical economical volume of production is around 75,000-1,00,000 pieces per die. After this the die wear causes component integrity to be lost. The economical volume of production of castings per die will be around 75,000 pieces.

The GDC process has several advantages. The process is suitable for mass production with better reproduction; dimensional accuracy and surface finish than conventional sand castings. A minimum wall thickness of 3.0 mm can be cast. Exceptionally, 2mm wall thickness is cast over small areas.

Castings ranging from few grams to ~100 Kgs of Aluminium alloy can be cast. There are reports of some foundries producing cylinder blocks of around 300 Kgs by GDC. As the component size and complexity increases the process becomes more expensive and becomes uneconomical. It will also cause difficulty in handling the die and in extracting the casting from the die with reduction in dimensional accuracy and soundness of the casting.

The GDC process is capable of achieving 20% higher mechanical properties than that of a sand casting because of faster rate of solidification imparting better grain size. The process can be automated and also can produce semi-gravity die-castings employing sand or plaster of paris cores for production of interior details.

The process has certain disadvantages. Limitation of geometry /size is a main disadvantage, as it is difficult to cast large size highly complex shapes. Beyond a particular shape and size the process becomes uneconomical. It is difficult to attach gates and risers at all desired locations. The casting yield is low when compared to other die casting process

The process is not suitable for steels and super alloys, because of their high pouring temperatures. Even in non-ferrous alloys, it is difficult to cast alloys having tendency for hot tearing like Aluminium-Copper alloys. These alloys having long freezing ranges tend to crack under faster rate of solidification.

In GDC, the tooling costs are higher than that for sand castings and hence will be uneconomical for smaller production quantities. Tooling modifications can be expensive.

Comparison of different casting processes.

		Sand Casting	**Gravity Die Casting**	**Pressure die Casting**
1	Tolerance (Min)	± 0.75 mm	± 0.5 mm	± 0.1 mm
2	Surface Finish	12 to 24 microns	4 to 12 microns	1 to 2 microns
3	Maximum Weight (Al alloy)	No limit	300 Kgs	10 Kgs
4	Max size (area) Al Alloy	No limit	800 x 500 mm	500 x 500 mm
5	Minimum wall thickness (Al Alloy)	3.5 mm	3.0 mm	1.0 mm
6	Production Quantity (EOQ)*	100	2000	100,000
7	Minimum Cored Hole size	10 mm	6 mm	2 mm
8	Machining allowance (min)	2.5 mm	1.5 mm	0.5 mm
9	Mechanical Properties (Scale)	1	1.25	1

*EOQ: Economical order quantity.

The process steps involved

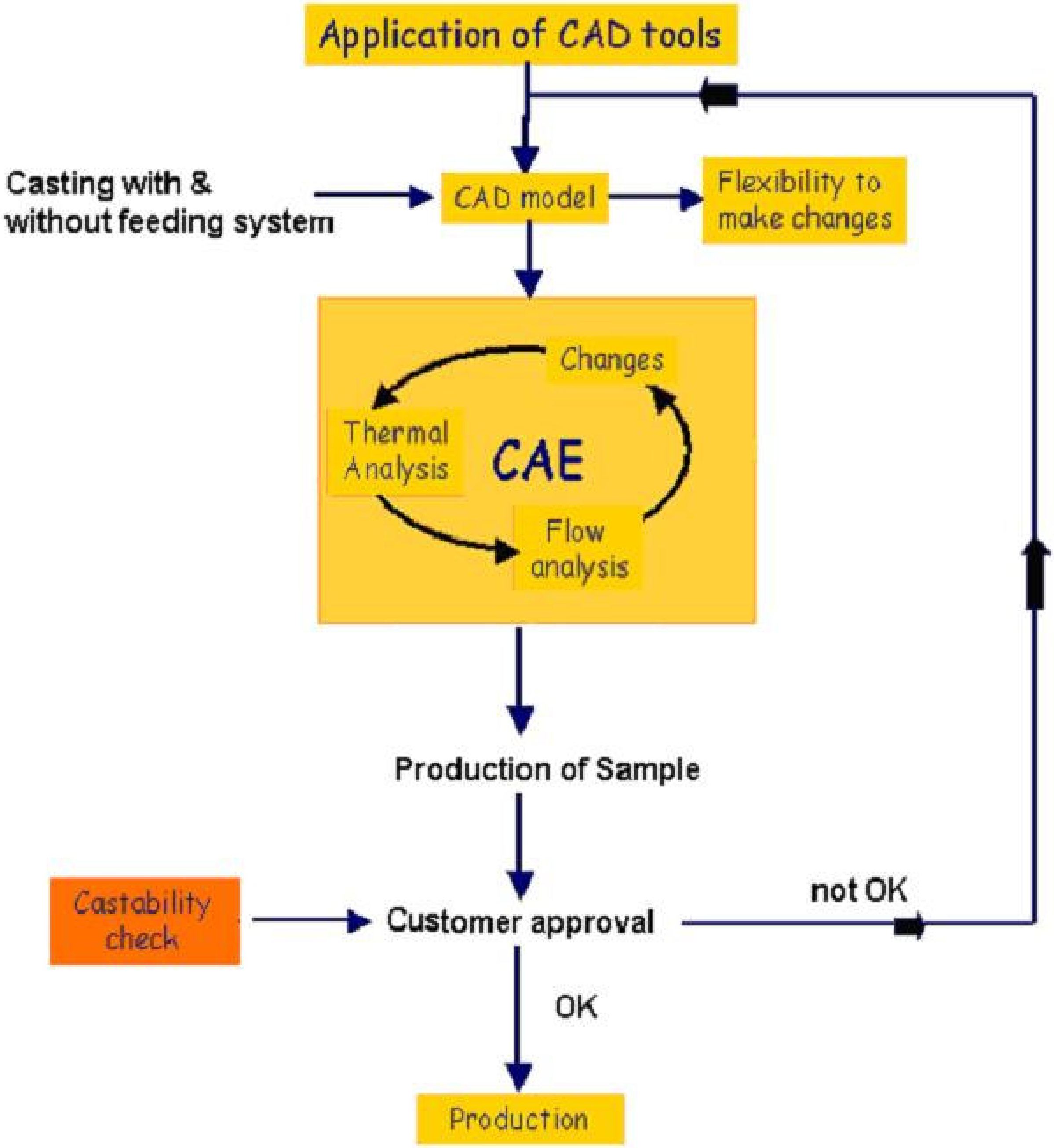

Figure 1 Flow pattern of computer simulation

Die Design by conventional method.

The die has to be designed so that the heat input to the die is to be dissipated before the next casting is poured. The die should also have adequate mass to act as heat sink, to avoid heat loss to the extent required during time lapse between castings. The heat input per cycle (which in turn has to be dissipated by the die) formula can calculate the thickness of the die required for effective cooling. In the conventional design, the heat input per cycle of casting is given by the formula:

$$Q = M.H_C (T_P - T_E) + M.H_L$$

Where,

Q = Heat input/cycle. (Cals. °C)
M = Weight of liquid metal poured (Gms)
H_C = Specific heat of the alloy. (Cals/gm. °C)
T_P = Pouring temperature. (°C)
T_E = Ejection temperature. (°C)
H_L = latent heat of fusion. (Cals/gm. °C)

One of the major drawbacks of the conventional formulae is that it does not take into account the local variations. For example the temperature at different points of the casting will be different in different regions, which is not accounted here in the formula used. When precision, quality and enhanced productivity are the issues in gravity die casting, such assumptions become very critical. The cooling rates in the die can be controlled with suitable alteration of cycle time, and /or by resorting to external cooling by air or water channels and so on.

Design of gates and risers by conventional method

A major factor in the successful development of castings is the design of the die and design of gates and risers. A well-designed gating system should avoid turbulence in metal flow and to reduce incidence of inclusions and air entrapment in the casting. Adequate feeders are required to avoid solidification related defects like shrinkage, micro-porosities, hot tears etc. The classical approach is to design through calculations of volume and surface area of various areas of the casting (modulus method). Volume represents the capacity to store heat and the surface area represents the capacity to transfer the heat to surrounding by convection. Higher the modulus means, more capacity to store heat (volume) compared to the heat loss by convection (surface area). For this reason, the modulus of the riser should be higher compared to the casting. For non-ferrous castings riser modulus is typically in the range of 1.3 to 1.4 compared to the modulus of the casting.

In the conventional method of gating design, the casting is split into number of hot zone areas depending on the hot spots identified from 2D sectional drawings of the casting. To these areas individual risers having higher modulus are attached. Such a process is very much dependent on the experience and skill of the design engineer. Also the identification of hot spots for complex shaped components is not always straightforward.

This involves rigorous calculations and casting proving trials to establish adequacy. Further this is based only on geometry and does not take into account thermal effects of mould media and heat saturation of cores. In a gravity die casting process, this becomes more complex, expensive and time consuming as any changes involves metal cutting and reshaping of metallic die.

Computer simulation based die design and gating design

Computer simulation of the casting process can overcome the limitations of / uncertainties involved in conventional calculations. Such techniques are widely adopted world over by large number of foundries. By doing the casting simulation on the computer all the physical processes including the flow of the molten metal, the heat transfer, solidification and shrinkage, and also formation of stresses are analyzed. Further, complete information on all these from the beginning of casting till the ejection are available in the complete 3D view of component. Designer can chose the section of interest and look at the results in more detail.

A typical flow of computer simulation based design is given in figure 1.

CAD of component

CAD of cast component

Castability check

Casting Process selection

Thermal analysis for prediction of hot spots

CAD of dies and gating

Meshing of Coupled flow and thermal analysis

Analyse the process for defects, yield etc.

Modify the gating, and die design.

Rerun the model and analyze the process for defects.

Finalize the die design and gating design by iterative loop of design, simulation and analysis.

Produce the dies and take shop floor trials.

Send the castings for testing and approval.

The design and gating design arrived at by such a procedure reduces significantly the product development life cycle and reduces the cost of development. By using the computer simulation as a virtual casting shop, the following can be achieved:

- Optimizing die design.
- Optimizing the gating and risering system.
- Prediction of defects such as shrinkage, porosities, hot tears, cold shuts, gas entrapment etc., for a given gating design.
- To enhance yield and reduction of scrap by understanding the problems with a given gating design and redesigning the gating.
- Process re-engineering.
- Estimate the stresses due to ejection and component failure.
- Estimate the microstructure of the component.
- As R & D tool to carry out experiments with different options, without resorting to actual casting trials.

Case studies

Computer simulation based design procedures described above have been implemented. Two case studies

1) A gear box casing
2) A manifold

are presented here in this article describing the steps involved in the procedure. The reader can visualize the benefits of the simulation procedure in producing sound castings quickly.

Case Study 1: Gear Casing – Aluminium alloy Gravity Die Casting

The Finite Element Analysis starts with 3D model of the casting without any feeding system attachments (for thermal analysis) or as cast model.

The model is discritized into small elements and Tetrahedral /wedge/ hexagonal mesh is generated. Thermal analysis is carried out on these models.

Figure 2 shows the 3D CAD model of the casting . Figure 3 shows CAD model of casting with mesh for thermal analysis. Figure 4 shows the thermal analysis showing the last regions to solidify (hot spots). In the analysis of hot spots there are two assumptions. 1) The die cavity is completely filled with the molten metal at the start of the simulation and 2) The temperature of the molten metal in die cavity is uniform (no heat loss during filling). With such an analysis, the selection of parting line, design of die, fixing of core locations and design of initial gating are facilitated.

Analysis of the initial gating design:

Figure 3 shows a meshed model with the gating system attached to the casting. Figure 5 shows in different views the fraction solid. Fraction solid is equal to '1' when 100% solidification has taken place and '0' when no solidification has taken place. If there is regions with fraction solid less than 1, which are surrounded by fully solidified (fraction solid=1) zones, it indicates that there are some problems.

Problem detected in gating design by proCAST simulation

A detailed analysis of the results of ProCAST simulation indicated that there are problems in feeding the bosses and regions below the riser as indicated in figure 5.The melt flow in die cavity has to be smooth and should not result in drastic temperature drop. Based on the simulation results, suitable alterations were made in the sprue, die thickness / section, and also in core design.

Modifications to the gating and die design (design-2)

Based on the analysis of simulation results, the following changes were made to the die design and gating system

a) Increase the modulus of the riser below which shrinkage was predicted.
b) Alterations in sprue, runner and gates for more uniform filling.
c) Extension of the hollow cylindrical riser to the flange area towards the sprue.
d) Alterations in the Die section thickness.

Simulation was carried out with the modified gating system. Figure 6 shows the fraction solid with the design-2 gating design. The detailed analysis showed a smooth flow of melt and a near sound casting. However the region below the square riser showed some region cut off from the feed path. At this stage a casting trial was taken. Figure 7 shows the photograph of the component with the defect as well as the corresponding section in simulation showing the defect.

Design-3

To overcome the above defect, a copper chill was provided in the design. The effect of copper chill on the casting quality is shown in figure 8. No defect was predicted. The design was frozen for trial. Trials indicated good quality castings, which are in production.

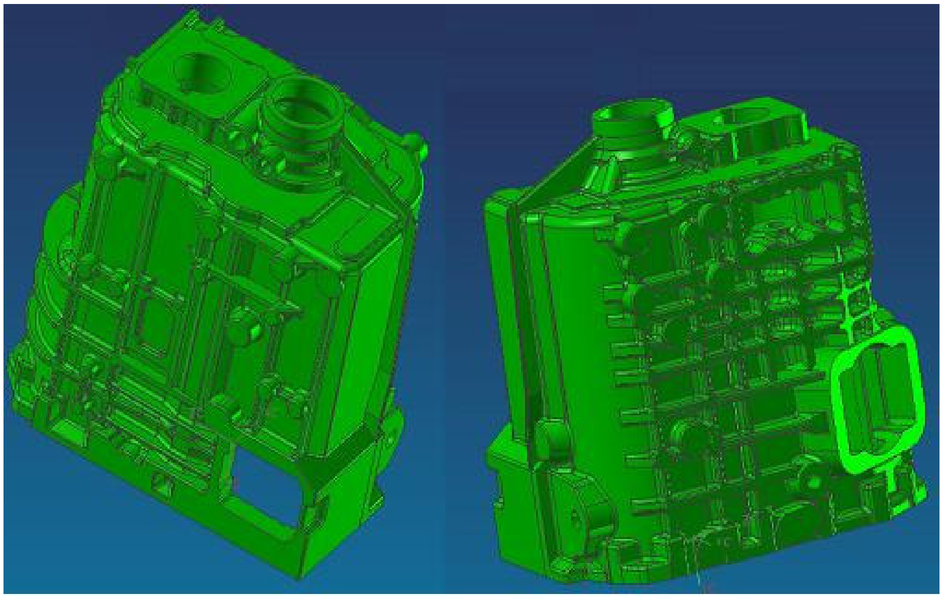

Figure 2 CAD model of Casting.

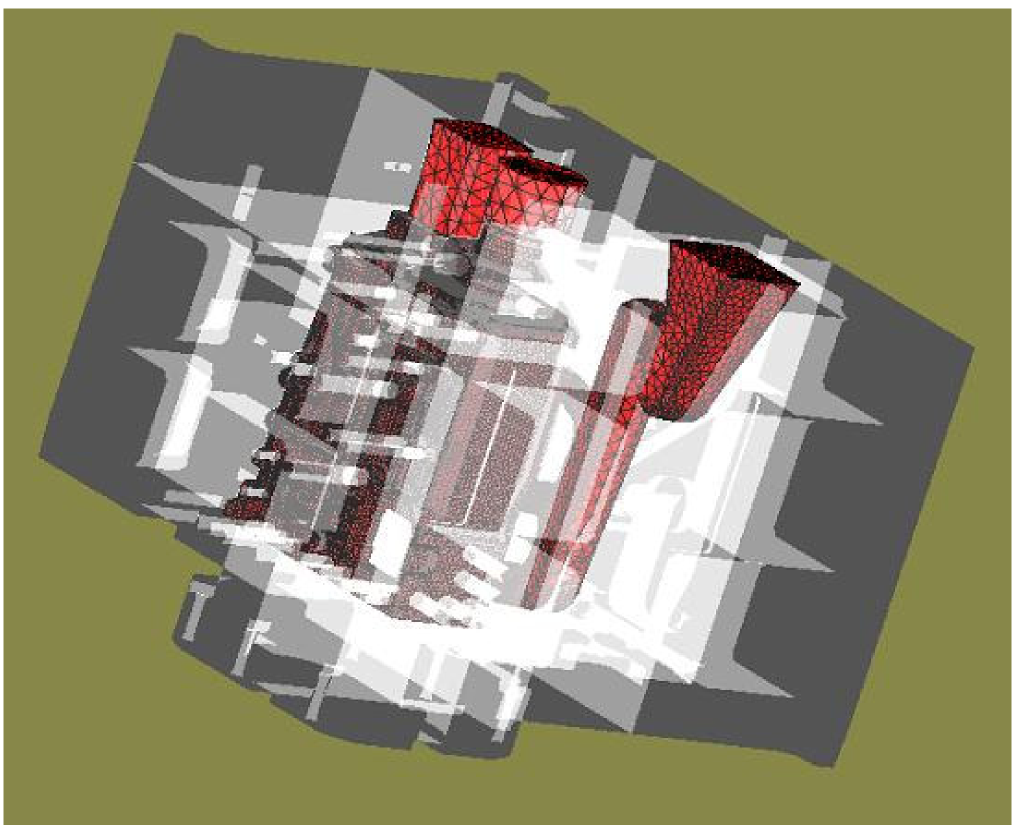

Figure 3 Tetrahedral Mesh generated for the component

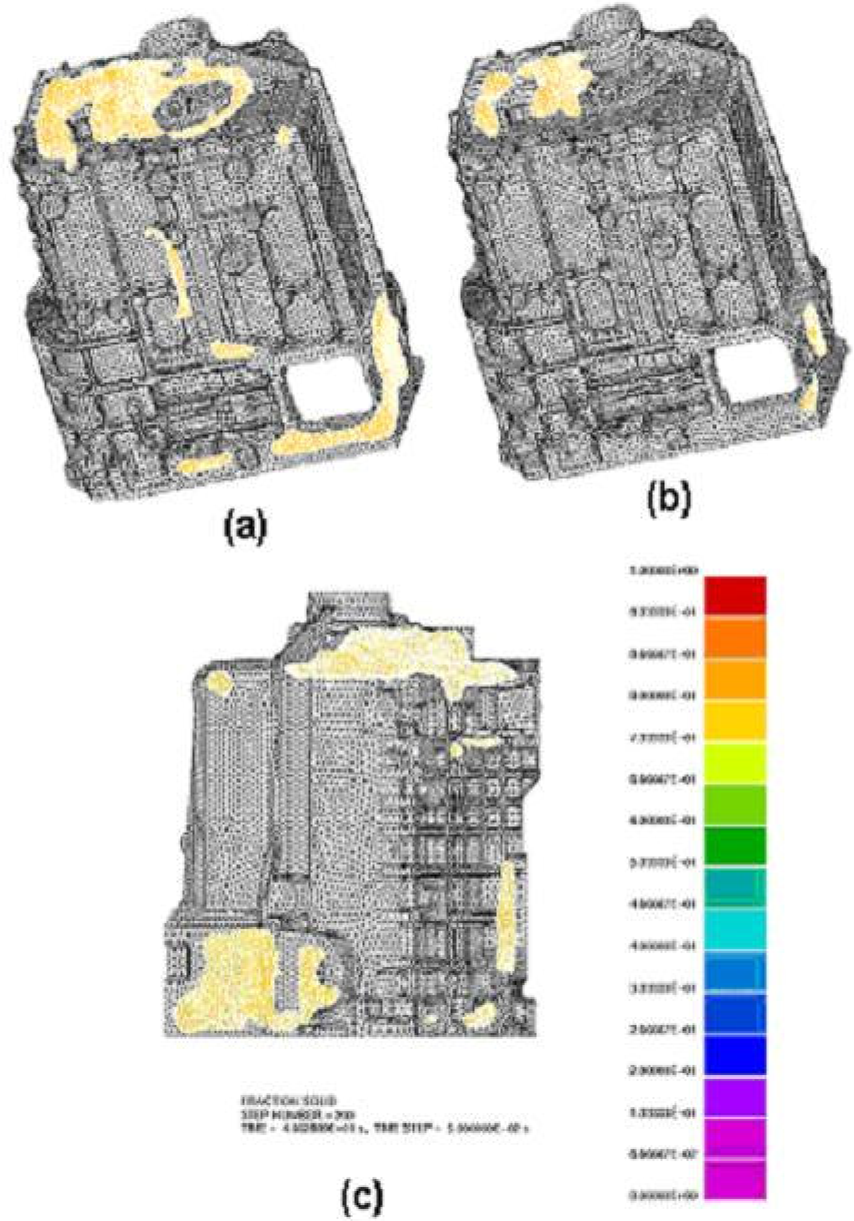

Figure 4 Thermal analysis using ProCAST software, a, b, c are different views of casting showing the last solidifying zones.

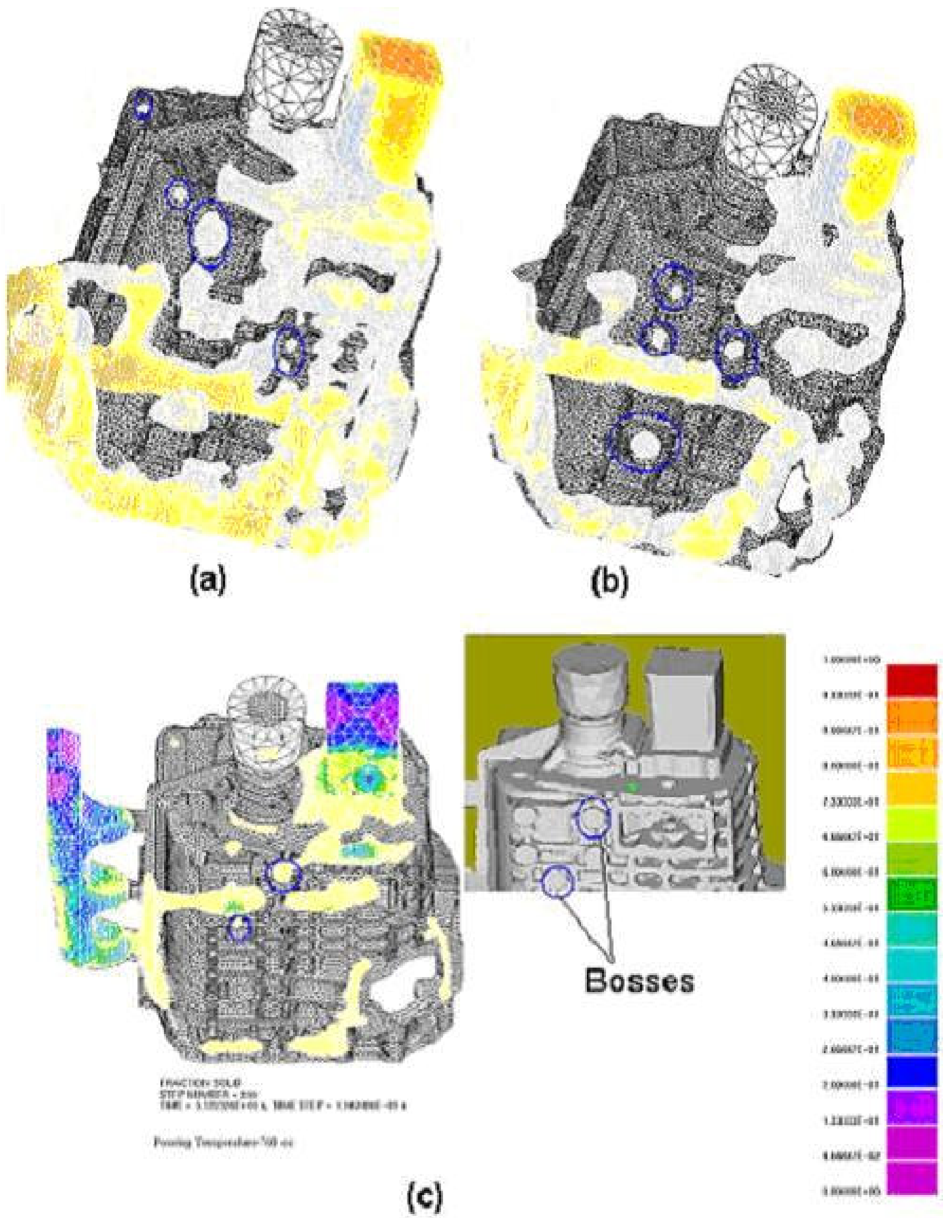

Figure 5 Fraction Solid regions cut off from feed path.
(Prospective regions prone for shrinkage)

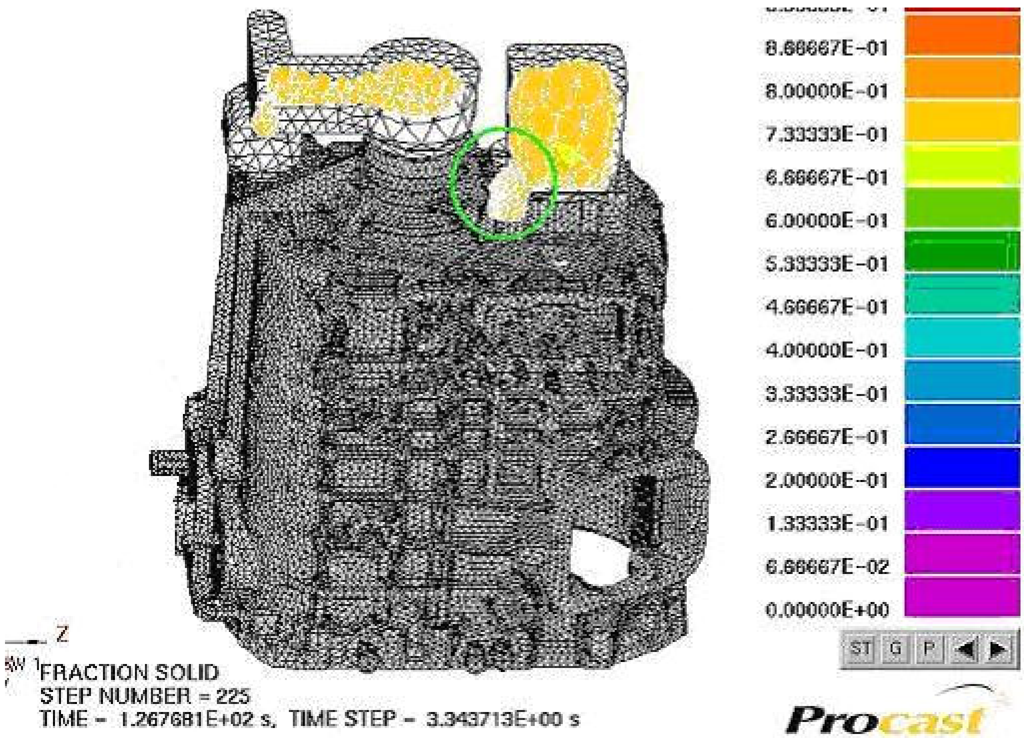

Figure 6 Simulation photo shows the changes made, clean feeding except for one region under the riser predicting shrinkage (marked in Circle).

Figure 7 showing the actual shrinkage defect under the riser.

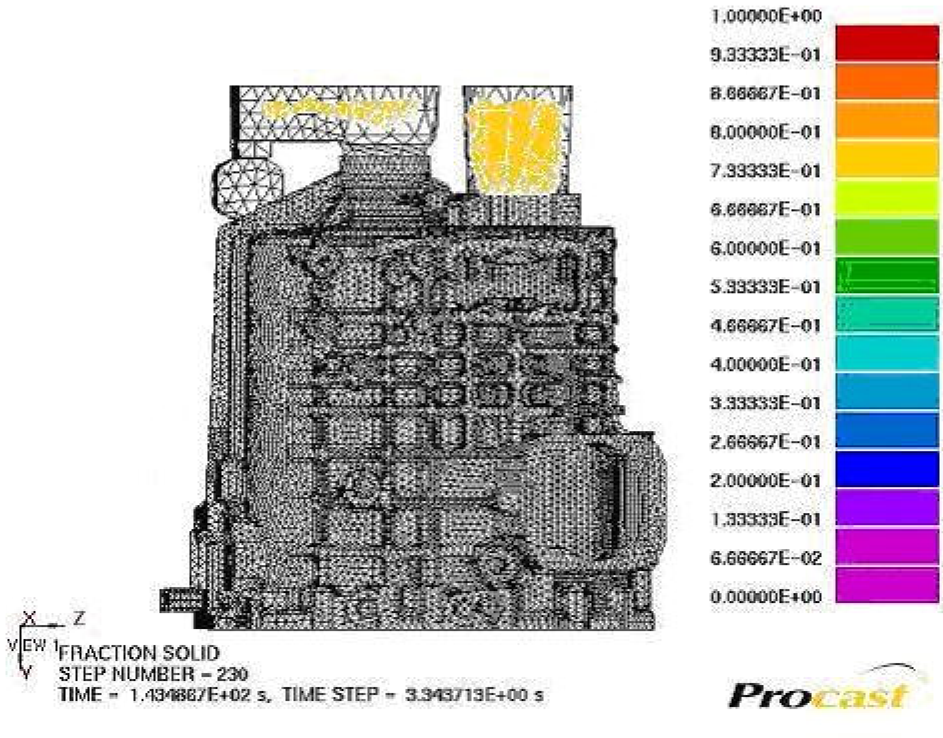

Figure 8 Simulation photograph showing defect free casting

Case Study 2: Aluminium Manifold Component – GDC

Figure 9 shows CAD model of casting with mesh for flow analysis.

Based on the Thermal Analysis, as explained in case study 1, an initial gating was incorporated and analyzed using ProCAST software. The fluid flow was satisfactory. The main concern shifted to the last areas of solidification. The bosses in the ports and the long chamber showed presence of shrinkage defect. These are depicted in figure 10 & 11

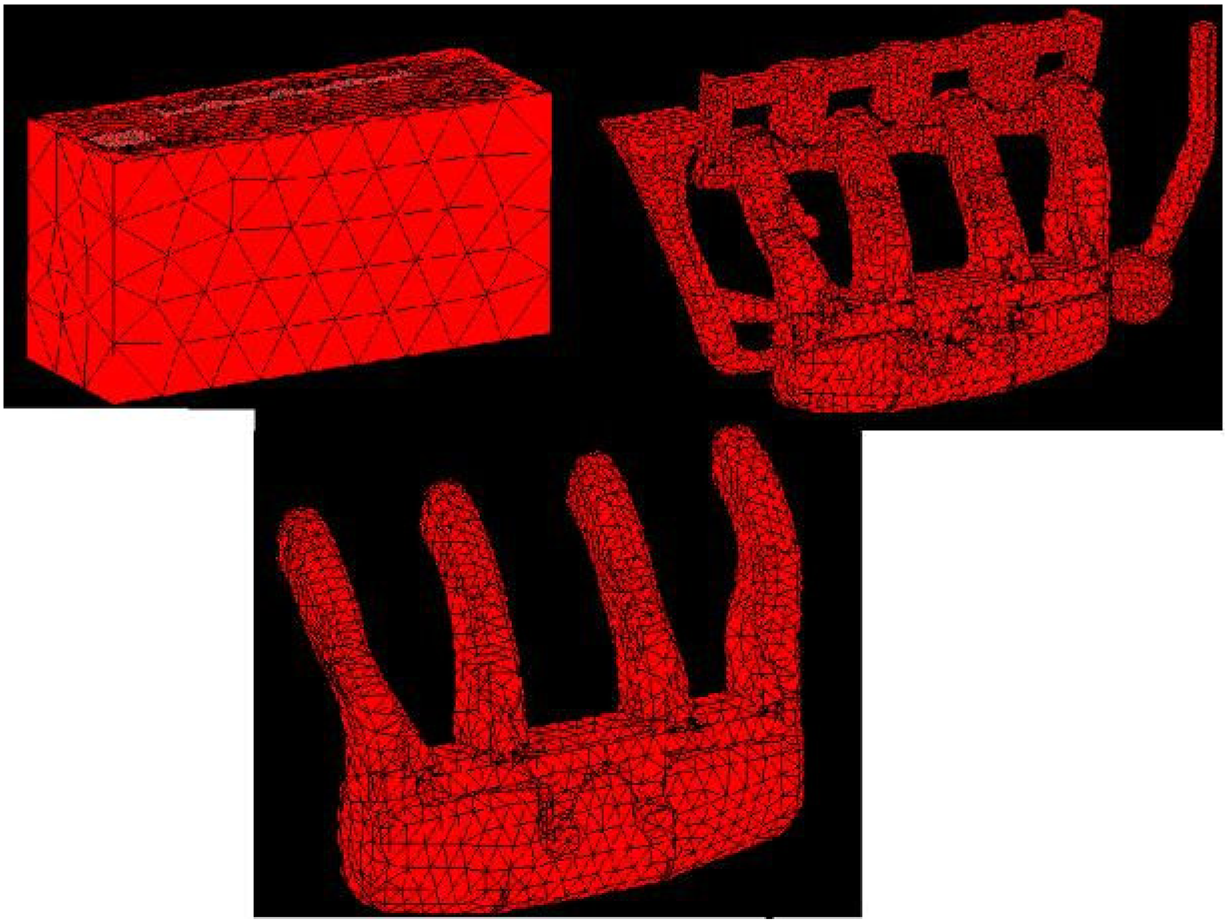

Figure 9 Tetrahedral Mesh generated for the casting, die and core

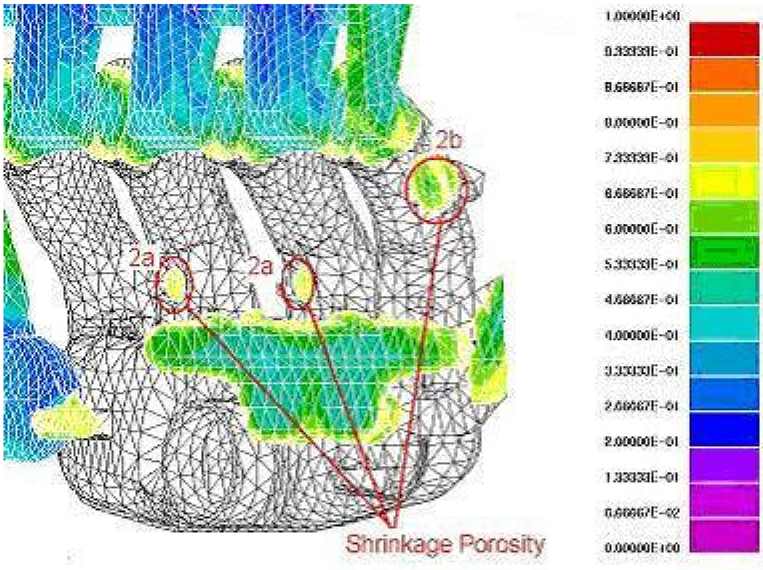

Figure 10 Shows porosity locations on the bosses in the ports.

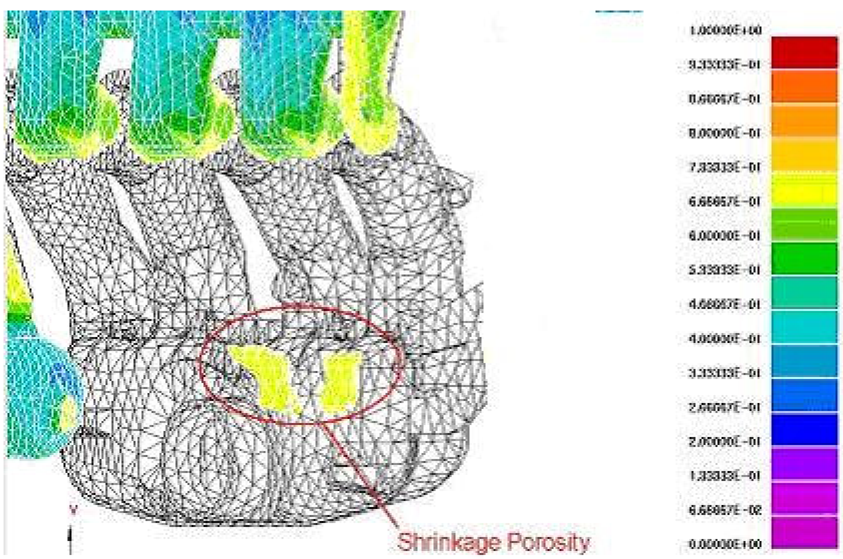

Figure 11 Shows porosity locations in the long Chamber.

These regions were inaccessible for providing adequate risers because of process limitations. Copper Chills were introduced on the bosses in the ports, and making suitable cutouts in the chamber area (see figure 12), to speed up solidification in these areas, made alterations in the die section thickness.

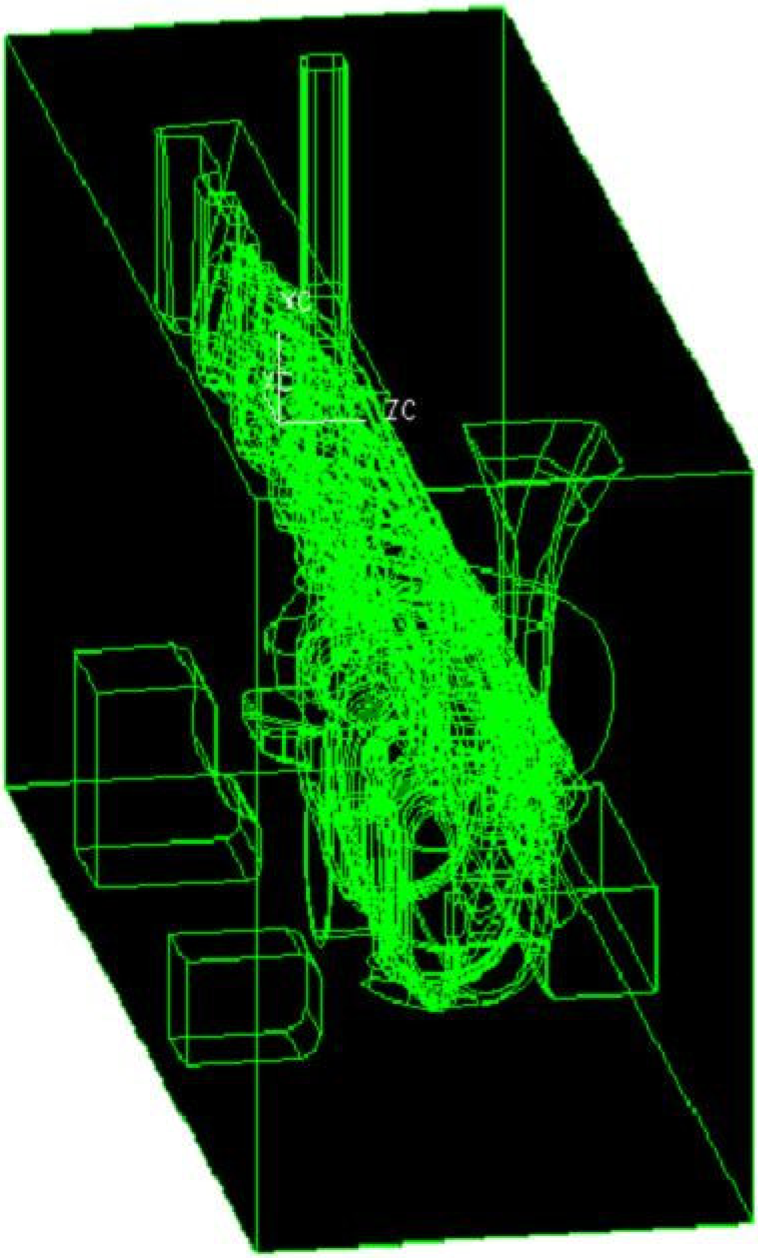

Figure 12 Die cut outs modifications

A Simulation was carried out with these modifications (design-2). While the copper chills proved to be effective, the chamber area still had some indications of shrinkage. The design changes were not fully effective and adequate. The locations are shown in Figure 13.This defect was eliminated, by effecting suitable process controls in the foundry.

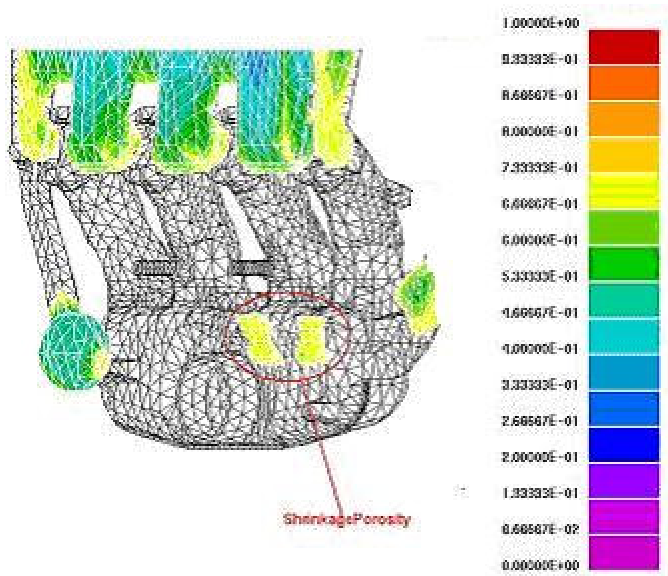

Figure13 Showing the areas of last Solidification in the chamber region.

Conclusion:

In gravity die casting of Aluminium parts, computer simulation can be a useful tool for rapid process development. Limitation of the conventional die design and gating design has been elaborated. Advantages of computer simulation based design enumerated. The procedures thus described have been demonstrated with two case studies of application of ProCAST simulation at Ennore Foundries. It is demonstrated that the foundries can derive mileage by resorting to FEM simulations of the casting process for process development and optimization.