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, appropriate design of casting and methoding (feeding and gating system) is necessary. The problems can be predicted and prevented by means of computer simulation of casting solidification. This paper discusses the simulation of casting solidification with the aid of an example, which will help foundry engineers and industrial metallurgists in understanding the temperature history of the solidifying casting, and in identifying the hot spot region with the aid of obtained time-temperature contours. These results will be used to get defect-free as-cast products by optimising the casting design based on findings attained from the simulation process. Foundries are supported by several software simulation packages which differ in terms of functionality, user interface, cost per simulation and prediction accuracy matching the radiographic shrinkage porosity levels specified by the customer.

Casting Simulation Programmes
Several casting simulation programmes are currently available in the market, offered by renowned companies from all over the world. These include AutoCAST, CAP/WRAFTS, CastCAE (Castflow, Casttherm), JSCast, MAGMASoft, MAVIS, Novacast (NovaSolid, NovaFlow), PAM-CAST, ProCAST, RAPIDCAST, SOLIDCast and others. One has to select the software based on his own experience in his own foundry.

Casting solidification simulation software are in regular use by aluminium, copper, iron and steel foundries using processes ranging from green sand, resin and shell-bonded sand to investment and gravity die-casting. Applications include large steel castings such as heavy weighing turbine housings and stern frames where improved yields and reduced fettling costs were achieved for critical high-pressure valve castings.

Various assumptions and constraints to be considered in casting solidification simulation are listed here.

Information about Metal
- The metal being cast such as steel, cast iron, ductile iron or non-ferrous.
- Working condition of the casting such as at high or subzero temperature.
- Working fatigue strength, thermal shocks to be sustained.
- Volumetric shrinkage of the cast metal during solidification.
- Melting point of the alloy and pouring temperature.
- Thermal conductivity of liquid metal during solidification of metal.
- Dissolved gases in liquid metal during melting process such as hydrogen, nitrogen and other gases which will affect the solidification.
- Composition of metal by spectroscope to find carbide forming elements which may affect solidification shrinkage.
- Centreline feeding capacity of liquid metal.
- Design of casting and weight, volume of casting.
- Effective feeding distance of any size of riser.
Design of Casting from Foundry Point of View

It is very beneficial if there is a meeting of customer’s design engineer, foundry person and a simulation expert so that all relevant information can be obtained for working out an efficient methoding layout as per the requirement of both foundry and customer. The design considerations include the following:

- Variation in sections throughout the casting.
- Avoiding sudden changes in sections in casting which creates hot spots.
- Proper radius to be provided at section changes.
- Not making castings hollow just to decrease weight since cores will be needed.

Moulding Processes used and Properties of Sands

- Parting line of the casting and location of defects in casting to be taken into consideration.
- Entire gating system with number of castings in one moulding box.
- Net yield of casting process before simulation process.
- Present moulding materials like green sand moulding.
- Core making process (shell moulding, sodium silicate, no-bake or cold box).
- Type of moulding and core making machines.
- Thermal heat transfer from liquid metal through mould surface into atmosphere as this will decide the cooling rates at various points in the casting.
- Thermal conductivity increased by using chills, paints at heavy sections.
- Properties of moulding and core sands such as permeability, shear strength, compressive strength and fusion point of sand.
- The number of cores used and the sand used for cores; if cores are solid or made hollow to improve cooling rate of surrounding metal, particularly in case of large shell cores.
- Total yield of casting before and after simulation process.

Case Study of Ductile Iron Casting

A foundry producing ductile iron (Grade 400/18) valve casting was facing heavy rejection during N.D.T. radiographic testing of shrinkage porosity of levels 5, 6 and higher. Originally, the foundry was producing eight castings per mould box (Fig. 2) to increase the production rate. The foundry was visited to study the entire moulding and design of gating system in detail. Then the locations of shrinkage porosity in the casting area were studied under microscope to find the root cause of defects. The chemical composition...
was carefully studied from the presence of carbides of manganese or other elements.

The gating and risering was the most important factor causing the defects. The original layout of the methoding was meant to increase the production rate of casting. Key observations are listed here.

1. Pouring was through one central open riser.
2. Other risers are connected to one main riser by runner in cope box.
3. The ingates were connected to casting under the runner in cope box.
4. The risers could not provide the feed metal to locations of defects.
5. There is no flow off on the top of each casting flanges.

Accordingly, it was decided to change the entire methoding layout. Only four castings per box were planned, with centralised pressure pouring through insulated riser (Fig. 3). It was decided to study the simulation of new system and then modify the pattern plate. If simulation shows any reduction in rejection, then other steps can be continued. It was also decided that the metallurgical quality of metal before and after magnesium treatment should be controlled precisely.

The first step was to check the thickness variation in the casting model (Fig. 4), which is visualised for identifying hot spots and possible shrinkage porosity, and helps in locating the feeder. Solidification simulation of the casting (Figs. 5 and 6) confirms the shrinkage location and distribution. An appropriate mould size is selected to place four castings, and they are connected to a central feeder as shown in Fig. 7. Each casting is connected to the central feeder through
two ingates, making a total of 8 ingates. Further, an insulating sleeve is placed around the feeder (Fig. 8).

Casting solidification simulation was then carried out for the new layout. The 3D see-through view of colour-coded temperatures inside the casting shows the hottest region in the central feeder (Fig. 9). The shrinkage porosity results also show that the defect is entirely in the feeder, and the castings are free of shrinkage (Fig. 10). Finally, the summary of the methods reports are captured and communicated to the pattern maker (Fig. 11).

**Observations and Improvement**

Three heats of castings were produced in the foundry with the new methoding layout. The following observations were made:

**Fig. 8:** Insulating sleeve is placed around the central feeder.

**Fig. 9:** 3D solidification simulation of all castings shows hot spot in feeder.

**Fig. 10:** Shrinkage porosity is now in feeder; all four castings are shrinkage-free.

**Fig. 11:** Summary of methods report to pattern maker.
i) It was clear that the gating system is working smoothly giving shrinkage-free castings.
ii) The total yield increased to 72%.
iii) The shrinkage porosity levels decreased to radiography level considerably.

After observing the actual castings on the shop-floor, it was decided to provide flow off on top of each flange in the castings. The pattern plates were changed as per requirement under our supervision. These operations are shown in Fig. 12.

The applications of flow-offs on each flange of castings completely eliminated possibility of shrinkage porosity. This was confirmed by casting simulation (Fig. 13). The radiographic testing of the casting showed that the shrinkage porosity was of the order of zero to one level, only in some castings. Most of the production gave sound castings free from shrinkage porosity.

**Conclusion**

A comprehensive simulation of casting solidification requires metal and design data. Proper communication between designer, customer and foundry expert helps in utilising simulation technology to achieve quality castings of any metal particularly steels, cast irons, ductile iron, austempered ductile iron and compacted graphite iron castings for global market to meet their specifications.