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Research Article

Application of Simulation Softwares for Analysing the Solidification Pattern of Aluminium Alloy (LM6) Casting

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Abstract: Casting simulation is a virtual casting process that ensures the production of defect less castings in the shortest possible time. It involves computer-aided modeling, pattern design, methoding, simulation and optimization. Casting simulation technology has been proven for all major cast metals and processes, giving reliable results even for complex castings. Neither a drop of hot metal is needed nor does it hamper the regular production schedule of the concerned foundry. It however, does not replace a methods engineer or production manager. It will only assist a methods engineer to achieve the best casting design with very few or even no trial and also creates confidence to a foundry manager. In the present study, a stepped component was considered to study the solidification behavior of LM6 at different size of the riser neck ,by using FEM based casting simulation software , whenever, the size of riser remains constant. The simulated results has compared with the experimental results. It has been observed that the simulated results are almost identical with the experimental data.
Keywords: Simulation, solidification, casting, riser neck, hot spot, shrinkage defect.

INTRODUCTION

In manufacturing process, casting is one of the most economical production processes, which involves considerable metallurgical and mechanical aspects. In casting process, the rate of solidification affects the microstructure of cast metal largely, which in turn controls the mechanical properties such as strength, hardness, machinability etc. of the cast metal. The proper of design of riser/feeder required to achieve directional solidification because wrong designed riser results either defective casting with shrinkage cavity or lower yield, as directional solidification has not achieved. Hence, proper design of risering system and good control over the process parameters are necessary for quality castings. However, the experimental routes are always better for design and development of mould and for arriving at the optimum process parameters. But, it is costly, time consuming, and may be impossible in some cases. Therefore, casting simulation process is a convenient way of proper design of risering system and analyzing the effect of various parameters.

The application of casting simulation increasing day to day in Indian foundry as it essentially replaces or minimizes the shop-floor trials to achieve the desired internal quality at the highest possible time. A number of casting simulation software are available today and the main inputs for the casting simulation are :

- The geometry of the mould cavity (3D model of the casting, feeders, and gating channels),
- Thermo-physical properties (density, specific heat, and thermal conductivity of the cast metal as well as the mould material, as a function of temperature),
- Boundary conditions (i.e. the metal-mould heat transfer coefficient, for normal mould as well as feed-aids including chills, insulation and exothermic materials),
- Process parameters (such as pouring rate, time and temperature)

There were lot of research work had been done on casting simulation by using different casting simulation softwares. Such as P. Prabhakara Rao *et al*. [4] studied on the simulation of mould filling solidification of casting of green sand ductile iron castings and concluded that the use of casting simulation software like ProCAST [1] can able to eliminate the defects like shrinkage, porosity etc. in the casting. It also improves yield of the casting, optimize the gating system design and the mould filling [2].

Dr. B. Ravi [5] Studied on optimization of mold cavities, feeders and gating system of an industrial component by using Auto cast casting simulation process. Author has shown that the total time for method design and optimization of the casting reduced to about one hour. Dr. B. Ravi [6] also studied on "Casting Simulation and Optimisation: Benefits, Bottlenecks, and Best Practices".

Dr. B. Ravi *et al.* [3, 7, 9] Studied on 3D Junctions in Castings: Simulation-based DFM analysis and guidelines, they have studied on defect like shrinkage porosity at casting of 3D junctions such as L/V, T/Y and X/K. Authors were predicted the location of shrinkage porosity by casting solidification simulation, and corrected by minor modification to part design. Author also investigates the best values and ratios of junction parameters by using casting simulation software like AUTO CAST.

ProCAST is based on the Finite Elements Method (FEM). It allows the modeling of Thermal heat transfer (Heat flow), including Radiation with view factors, Fluid flow, including mold filling, Stresses fully coupled with the thermal solution (Thermo mechanics). Beside that, it includes also microstructure modeling and porosity modeling. The numerical simulation of solidification involves the following steps:-

- Formulation of an accurate mathematical model of the solidification process
- Specifying accurate values for thermal properties of material involved.
- Performing the analysis to obtain the temperature history of casting and mould points.
- Post- processing the results to visualize the solidification pattern and identify defects in the casting.

In the present study, a stepped component was considered to study the solidification behavior of LM6 at different size of the riser neck ,by using FEM based casting simulation software i.e. Pro CAST , whenever, the size of riser remains constant. The simulated results were compared with the experimental results. Author also detects the level of porosity, location of hotspot and rate of solidification of metal with respect to time.

SOLIDIFICATION OF CASTINGS

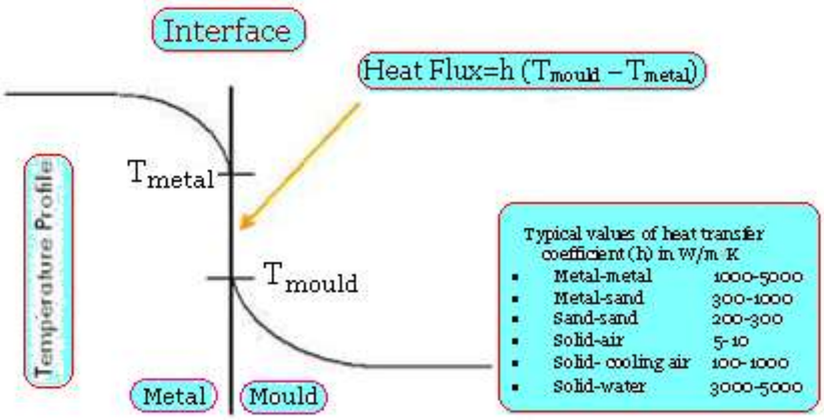
The solidification of the molten metal in the mould takes place due to thermal gradient in between the metal and mould [8]. The heat transfer from the metal to mould follows an unsteady heat transfer equation i.e.

$$\rho Cp\left\{\frac{\partial T}{\partial \tau}\right\} = K\left[\left\{\frac{\partial T^2}{\partial x^2}\right\} + \left\{\frac{\partial T^2}{\partial y^2}\right\} + \left\{\frac{\partial T^2}{\partial z^2}\right\}\right]$$

Where, ρ= Density of the metal,
$C_{p=}$ Specific heat at constant pressure,
K= Thermal conductivity of the metal.

The heat flux across the metal – mould interface= h x ΔT

Where, h= heat transfer co-efficient in W/m^{2}K.
ΔT= Temperature difference across the interface in ^{0}C.



Solid-liquid Interface

The energy balance has obtained by equating the rate of heat removed from the solid phase to the sum of the rate of heat supplied to the interface from the liquid phase and the rate of heat liberated at the interface during solidification. Hence, K_{sc} and K_{lc} are the thermal conductivity of the solid and liquid metal respectively. The 'L' denotes the latent heat, n denotes the normal to the surface (Direction of heat transfer) and s denotes fraction solidified (That release the latent heat).

$$-K_{sc}\ \frac{\partial T_{sc}}{\partial n} = -K_{lc}\ \frac{\partial T_{sc}}{\partial n} + \rho_{sc}\, L\ \frac{\partial s(\tau)}{\partial n}$$

Casting-Mould Interface

Before the air gap formation, heat has transferred by conduction. Given T_c and T_m are the temperature of the casting and mould; the temperature at casting mould interface can be found from heat flux **ω**

$$\omega = K_c \frac{\partial T_c}{\partial n} = K_m \frac{\partial T_m}{\partial n}$$

After air gap formation, heat transfer is by convection and radiation. Thus the heat flux equation in between casting and mould side is

$$\omega = \sigma \varepsilon F[(T_{sc} + 273)^4 - (T_{ms} + 273)^4] + h_g \Delta T = -K \left(\frac{\partial T}{\partial n}\right)$$

Where, T_{cs} and T_{ms} are the temperature at the casting and mould side of the interface, σ is the Boltzman's constant, ε is the emmissivity, and F is the form factor.

Outer Surface of the Mould

The heat transfer in between outer surface of the mould and atmosphere is take place by convection. Thus, the heat transfer equation between outer surface of the mould and atmosphere is

$$-K_m \frac{\partial T_m}{\partial n} = h(T_{ma} - T_a)$$

Where, T_{ma} is the temperature of the outer surface of mould and T_a is the ambient temperature.

METHODOLOGY

Figure-1 shows a flowchart, in which 3D CAD of the complete casting part and simulation tools have utilized to get better the system design of the casting. The casting geometries presented here are meshed with Mesh CAST, which requires the generation of a surface mesh before meshing the enclosed region with tetrahedral elements. The computational conditions used in all simulations were the same. Figure-2 shows a flowchart, which gives the steps required to make a simulation.

The results of solidification simulation include colour-coded freezing contours at different instants of time starting from beginning to end of solidification. This provides a much better insight into the phenomenon compared to shop-floor trials (real moulds being opaque). The user can verify if the location and size of feeders are adequate, and carry out iterations of design modification and simulation until satisfactory results have obtained.

Fig-1: Procedure to improve the quality of casting

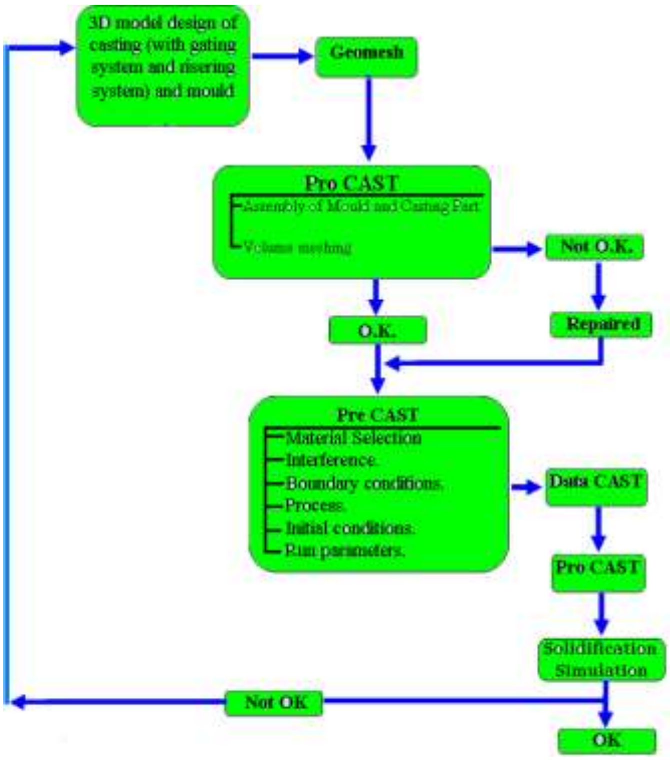


Fig-2: Flow chart of Pro CAST casting simulation

RESULT AND DISCUSSION

Analysis of mould filling by simulation process

The gating design has driven by the ideal mold filling time, which depends on the cast metal, casting weight and minimum wall thickness. Fast filling leads to turbulence-related defects (such as mold erosion, air aspiration and inclusions). On the other hand, slow filling may cause defects related to premature solidification (such as cold shuts and misruns). To optimize the gating design, the program simulates the mold filling and computes the total fill time.

The Pro cast simulation has solved for mould filling and solidification processes at the same time. The discussion about mould filling has solely based on Pro CAST simulation results. In the present investigation, a benchmark study on stepped (three) casting has considered and four 3D models of the casting has prepared with their gating and risering system by using solid works software with different size of riser neck at constant size of riser. The size of riser and its neck of different models have given in the Table-1. The mould filling processes at different step has visualized from Figs. 4, 12, 19 & 26 at different models. It has found that for every succession of one-second the fraction of solid and temperatures are changing (encompasses Sprue, ingate, casting and feeder) will be filled up. Due to the design of straight ingate system, the molten metal enters the mould through gate and rises almost uniformly in the cavity of the mould until it has completely filled up. This is a good filling because it ensures no sand erosion in the mould and solidification of liquid metal immediately starts in the mould cavity. On changing the dimension of the riser neck, the total mould filing time is not so much changed. The total mould filling time is within 798 sec. to 803.5 sec. in case all models.

Table 1: Size of riser and its neck of different models

	Riser Height	Riser Diameter	Neck Height	Neck Diameter
Model - 1	72.40 mm	47.98 mm	6 mm	47.98 mm
Model - 2	72.40 mm	47.98 mm	6 mm	40.70 mm
Model - 3	72.40 mm	47.98 mm	6 mm	28.70 mm
Model - 4	72.40 mm	47.98 mm	6 mm	22.00 mm

Analysis of solidification of casting

The solidification of liquid metal in the mould cavity takes place immediately after the entering of molten metal into the cavity. For the cast material aluminium alloy (AlSi13), solidification will start when the temperature drops below 572^0C, and fully completed beneath 570^0C. Solidification is a result of heat transfer from internal casting to mould material and then to environment. As it was a stepped casting, the rate of solidification is not uniform through the casting. The Fig.9, 16, 23 and 30 shows the change in temperature of the molten metal within the mould with respect to time in second. The temperature of the molten metal in the mould cavity drops with time. The solidification of liquid metal in the mould cavity starts from the edges of the casting and it progress towards the center of the casting. The solidification front directed from the thinnest section towards the thickest section and the thinner section solidifies much quicker comparison to the thickest section. The position of hotspot detected in different casting models. It has observed that the position of hotspot changed due to change in size of riser neck keeping the riser size constant and the dimensions of shrinkage defects are also different at different riser neck.

The Fig.5, 13, 20 and 27 indicates the temperature distribution and fraction of solid at different step. This Figures shows that the distribution of temperature and fractions of solid changes with respect to time at different size of riser neck. The position of hotspot in the casting also changes due to change of size of riser neck. It has found that in model-1, the hot spot is present at the bottom of the riser neck and shrinkage defect is present within the casting, where the size of riser neck is 22.0mm. The Fig.10, 17, 24 & 31 shows the graphical representation of fractions of solid Vs time. These graphs indicate the changes in fraction of solid formation within the casting with respect to time. It has been also observed that due to change in the size of riser neck, the temperature distribution and fraction of solid with respect to time not so much affected. The Fig.8, 15, 22 & 29 indicates the micro porosity defects in the casting.

Model-1

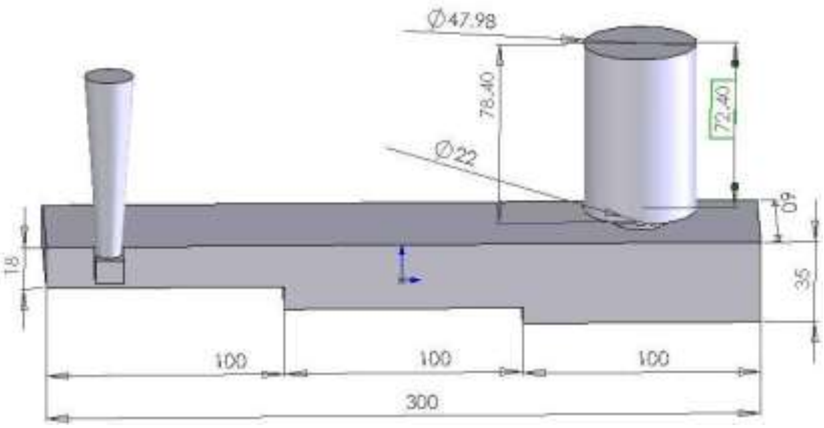


Fig-3: 3D model of the casing part with its risering system

Simulated result of model-1
Mould filling

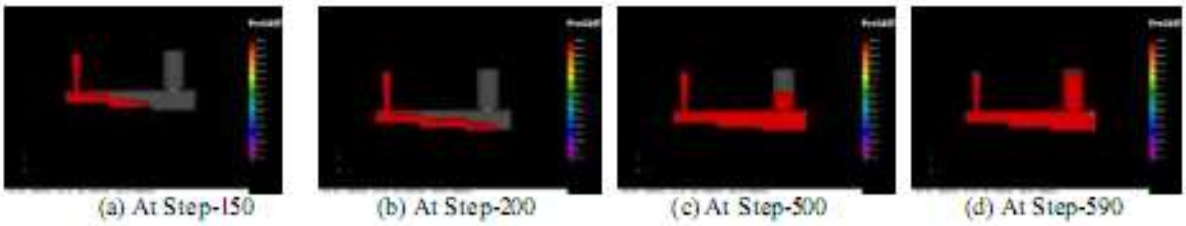


Fig-4: Mould filling at different step, a- d

Fraction of solid at different step

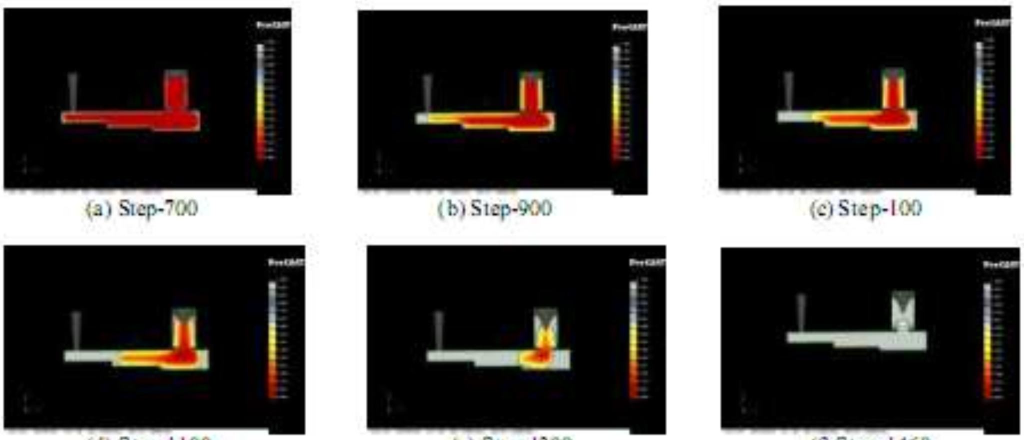


Fig-5: Fraction of solid at different step, a- f

Fig-6: Casting of model-1

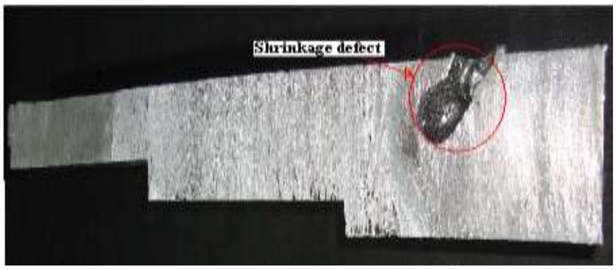


Fig-7: Section of casting with shrinkage defect

Fig-8: Porosity in the casting

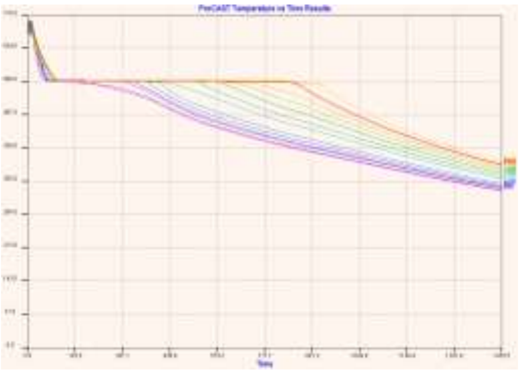


Fig-9: Temperature Vs Time

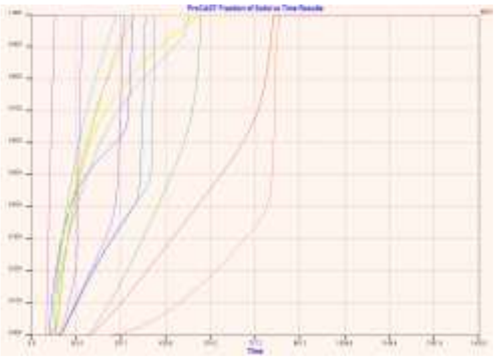


Fig-10: Fraction of Solid Vs Time

MODEL-2

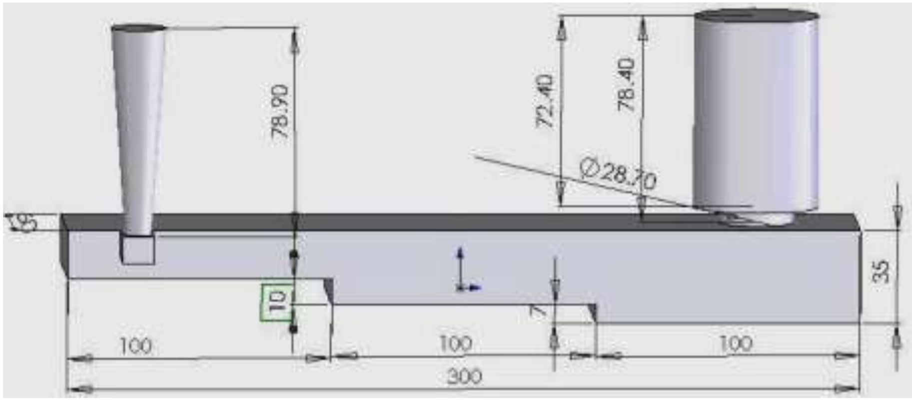


Fig-11: 3D model of the casing part with its risering system

Simulated result of model-2
Mould filling

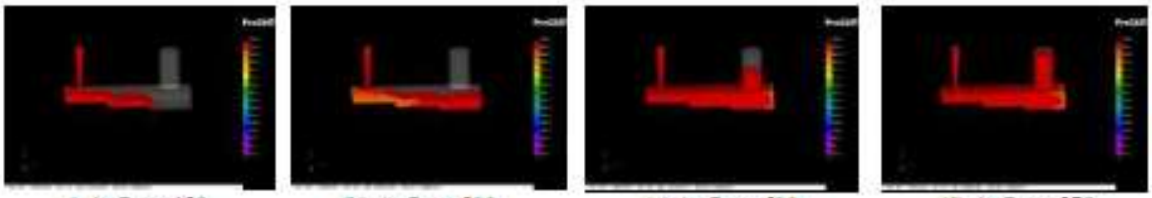


Fig-12: Mould filling at different step, a- d

Fraction of solid at different step

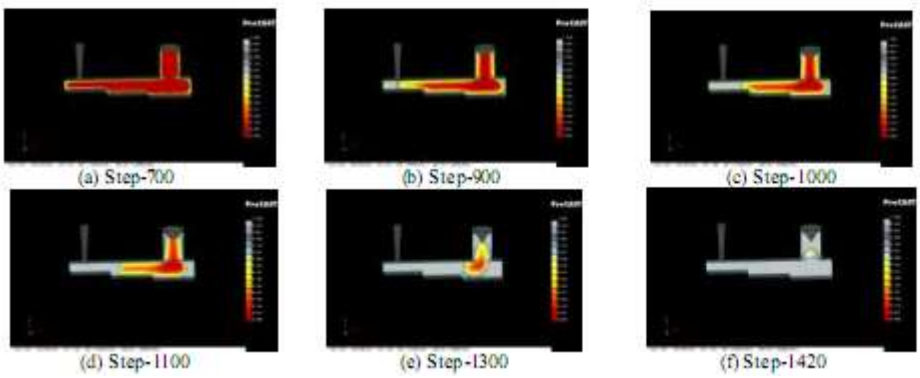


Fig-13: Fraction of solid at different step, a- f

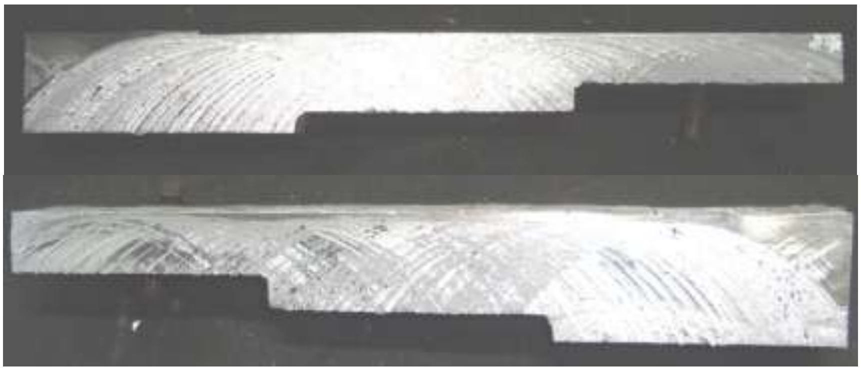


Fig-14: Section of casting shows no shrinkage defect

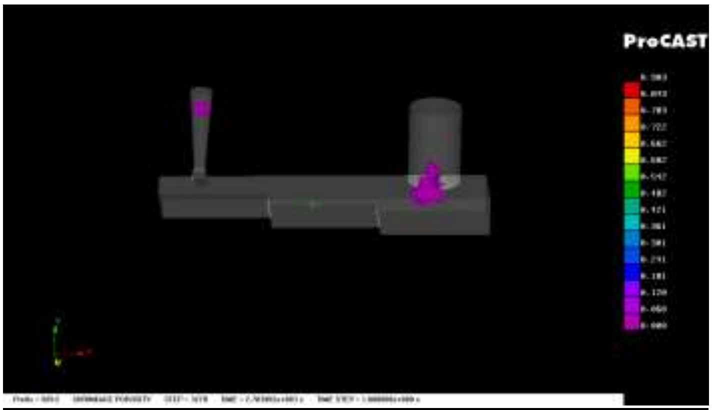


Fig-15: Porosity in the casting

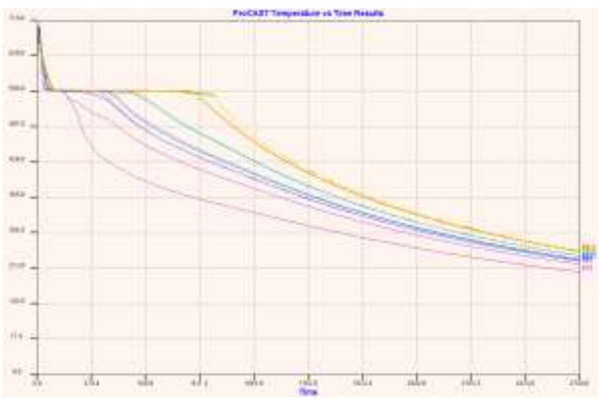


Fig-16: Temperature Vs Time

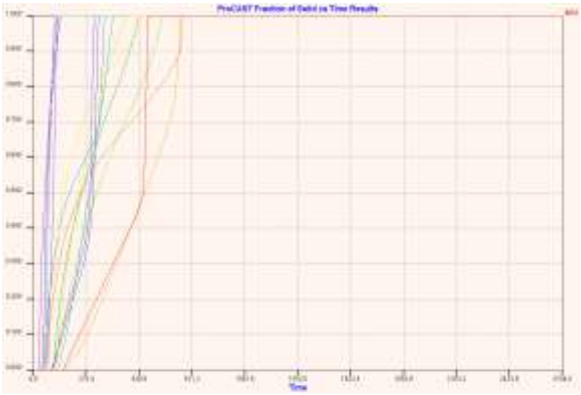


Fig-17: Fraction of solid Vs Time

Model-3

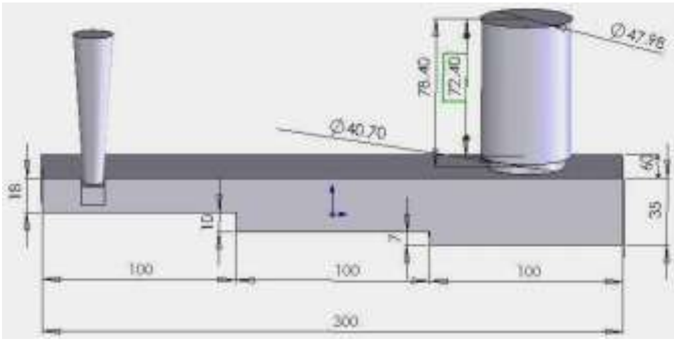
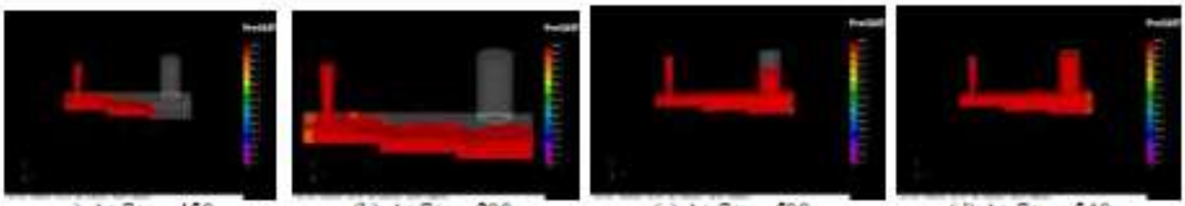


Fig-18: 3D model of the casing part with its risering system

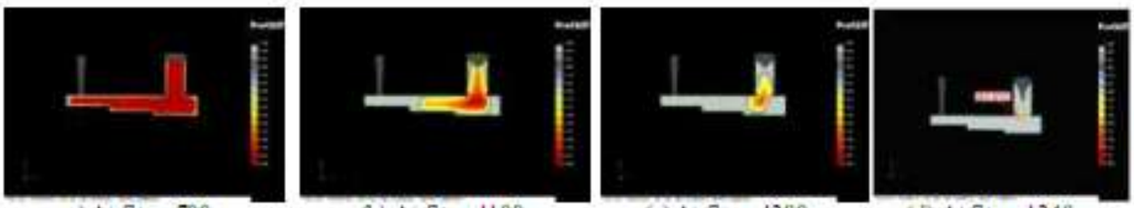
Simulated result of model-3
Mould filling



a) At Step-150 (b) At Step-200 (c) At Step-500 (d) At Step-540

Fig-19: Mould filling at different step, a- d

Fraction of solid at different step



a) At Step-700 (b) At Step-1100 (c) At Step-1300 (d) At Step-1340

Fig-20: Fraction of solid at different step, a- f

(Hotspot is present at bottom of the riser neck)

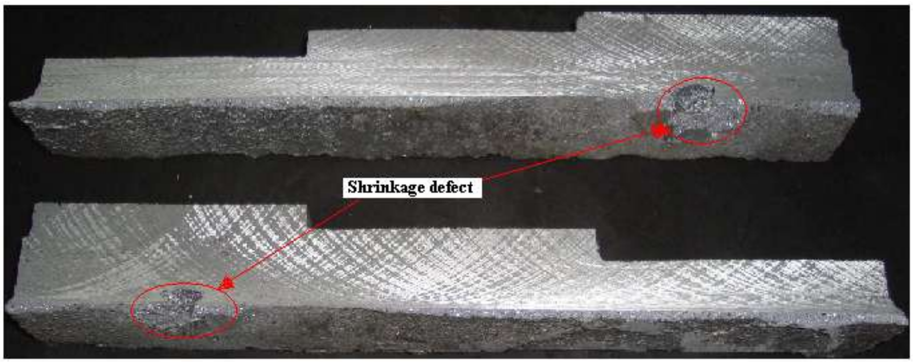


Fig-21: Section of casting with shrinkage defect

Fig-22: Porosity in the casting

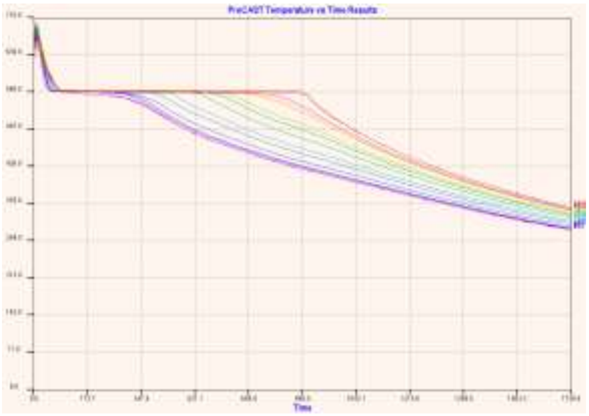


Fig-23: Temperature Vs Time

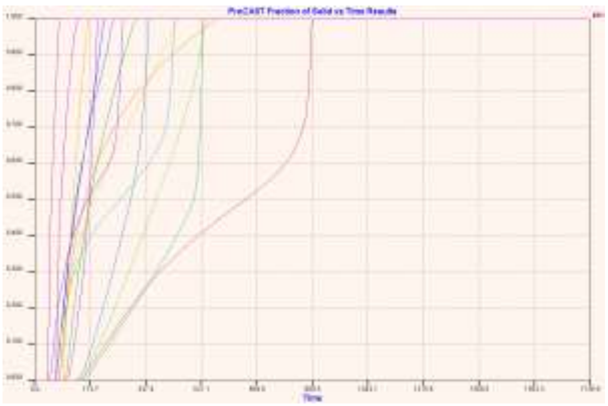


Fig-24: Fraction of solid Vs Time

MODEL-4

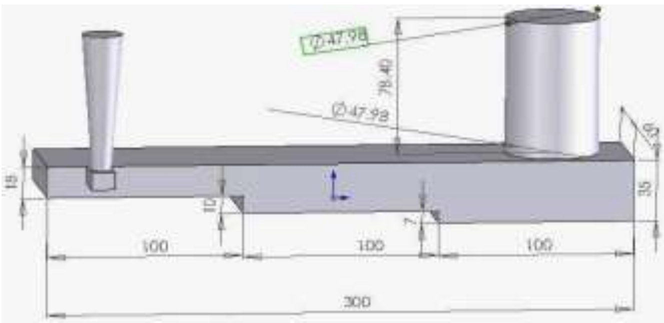
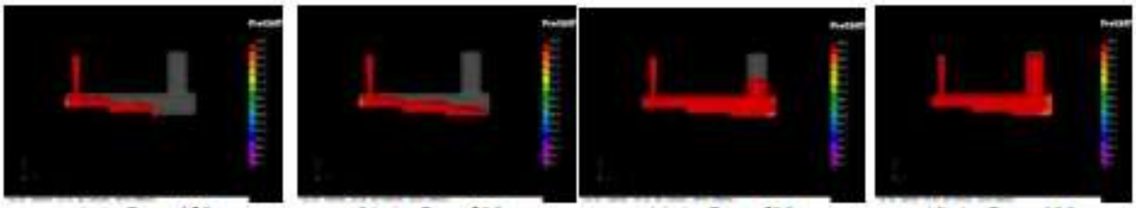


Fig-25: 3D model of the casing part with its risering system

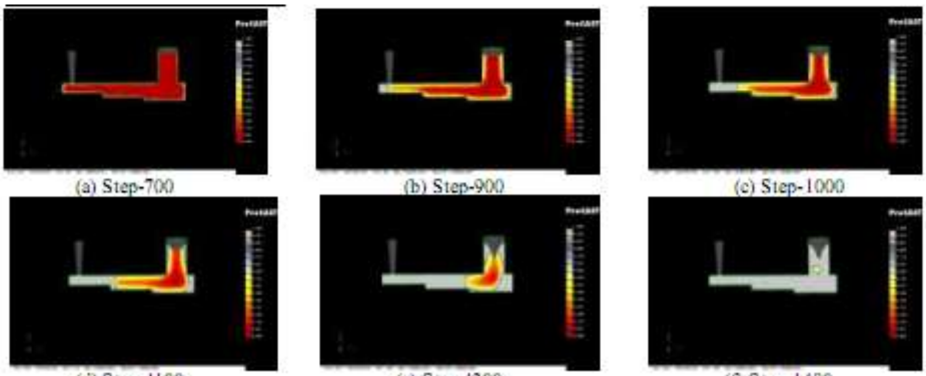
Simulated result of model-4
Mould filling



a) At Step-150 (b) At Step-200 (c) At Step-500 (d) At Step-600

Fig-26: Mould filling at different step, a- d

Fraction of solid at different step



(a) Step-700 (b) Step-900 (c) Step-1000

(d) Step-1100 (e) Step-1300 (f) Step-1480

Fig-27: Fraction of solid at different step, a- f

Fig-28: Section of casting shows no shrinkage defect

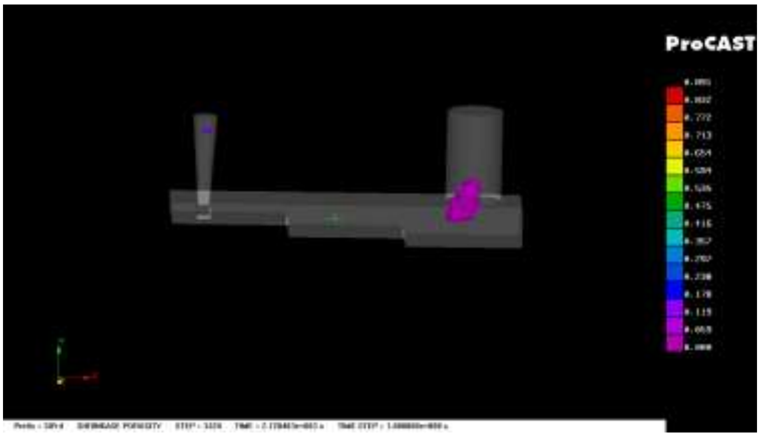


Fig-29: Porosity in the casting

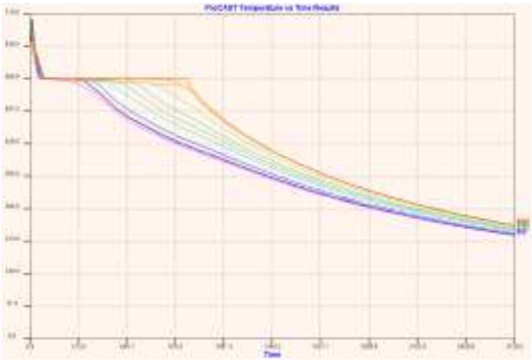


Fig-30: Temperature VS Time

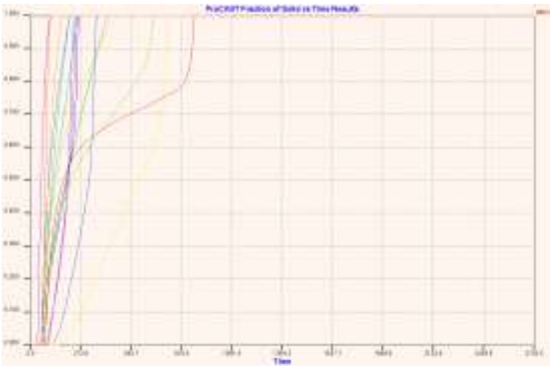


Fig-31: Fraction of solid VS Time

EXPERIMENTAL VALIDATION

After the results obtained by the simulation, stepped casting moulds has been prepared with green sand mould and molten aluminum alloy (LM-6) was poured into it. A number of castings were made with same size of riser (H = 72.40 mm x D = 47.98) with different neck geometry. The castings were sectioned approximately down the middle of the casting, to see if the macroporosity is visible. Figures 6, 7, 14, 21 and 28 shows the cross section of the castings and we observed that the macro shrinkage or porosity inside the casting. It has been observed that at riser neck of height (h) =6.0mm & diameter (d) =28.70mm with the same riser no shrinkage defect/ porosity is present in the casting. On decreasing or increasing the diameter of riser neck from the value the shrinkage defect occurred in the casting. This experimental result is more or less matching with the simulated results.

CONCLUSION

The application of casting simulation softwares in the foundries not only minimizes the wastages of resources required for trial castings, but also improves/ enhances the quality and yield of castings, which implies higher value addition and lower production cost. ProCAST is a very high ended software and it has ability to produce reliable simulation results that actually reflect the real casting phenomena. The benchmark study represents the effect of size of riser neck on the solidification behavior of the aluminium alloy castings and the position & size of shrinkage defect in the casting changes at different riser neck. The simulated results have more or less similar with the experimental results.

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