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Simulation of vertical centrifugal casting using ANSYS

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Abstract

Axis-symmetric products are often made by means of centrifugal casting, which involves heating and transferring molten metal into a rapidly rotating mould. Centrifugal casting defects are mostly associated with the solidification process. However, when employing experimental techniques for centrifugal casting, determining the process of solidification pace and duration is quite challenging. Simulations may be used to analyze and optimize operational conditions.

Keywords: Vertical Centrifugal Casting; Casting Defects; Computational Fluid Dynamics; Volume of Fluid; Enthalpy-Porosity Model; Standard K-ε model

1. Introduction

Casting is an old traditional technique in which a liquid material is poured into a mold; the mold is a hollow cavity. Then it can solidify and part that is called casting. The casting is then ejected out of the mold to complete the process. In the process of centrifugal casting the mold spins itself during the time, the casting is solidifying. First the metal is being poured while the mold is spinning. It differs in case of vertical centrifugal casting and horizontal centrifugal casting. In vertical centrifugal casting we sometimes prefer the mold to be stationary when the metal is being poured. After the metal is being poured then the machine accelerates the metal.

While in horizontal centrifugal casting the mold is expected to be rotated at a lower speed during pouring. After the pouring is done the mold is being rotated at a rapid speed. Centrifugal casting gives better mechanical properties compared to another casting method. Basically iron, steel, stainless steel, glass, and alloys of aluminum, copper and nickel. The process is used for manufacturing of cast iron tubes, pipes, cylinder liners and axis-symmetric parts.

We perform the casting simulation to minimize the defect. It is a virtual process of real time casting process. We can also visualize and simulate the entire casting process. ANSYS is the software we are using for the simulation of casting.

Melted metal is put into a mould that is spinning quickly in centrifugal casting. After full solidification, the molten metal is distributed throughout the mould surface by the centrifugal force created by spinning, resulting in the formation of a hollow, cylindrical-shaped casting. Mould rotation can occur on a vertical or horizontal axis. As soon as the melt first contacts the mould wall, solidification takes place. In the vicinity of the mould, a cloud of tiny crystals forms. A extremely thin structure is created throughout the bulk as a result of the nuclei's uniform distribution and the forces of inertia and severe shear force interacting. Most of the nuclei survive and continue to develop in this environment. Usually, intense tangential flow washes off any potential columnar crystals that crystallize from the mould wall.

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2. Literature review

2.1. Casting

Casting is an old traditional technique in which a liquid material is poured into a mold; the mold is a hollow cavity. Then it can solidify and part that is called casting. The casting is then ejected out of the mold to complete the process. In the process of centrifugal casting the mold spins itself during the time, the casting is solidifying. First the metal is being poured while the mold is spinning. It differs in case of vertical centrifugal casting and horizontal centrifugal casting. In vertical centrifugal casting we sometimes prefer the mold to be stationary when the metal is being poured. After the metal is being poured then the machine accelerates the metal.

While in horizontal centrifugal casting the mold is expected to be rotated at a lower speedduring pouring. After the pouring is done the mold is being rotated at a rapid speed. Centrifugal casting gives better mechanical properties compared to another casting method. Basically iron, steel, stainless steel, glass, and alloys of aluminum, copper and nickel. The process is used for manufacturing of cast iron tubes, pipes, cylinder liners and axis-symmetric parts.

2.2. Mode of solidification

Solidification in centrifugal castings is a similar process to that occurring in static castings i.e. are a change of state phenomena, the rate of which is governed by heat transfer, but there are super-imposed effects of the mechanical action [Howson, 1969].

Melted metal is introduced into a rotating mould during the procedure of filling as well as solidification of the casting, which is the fundamental process of centrifugal casting. A wide range of ferrous and non-ferrous alloy components are produced using centrifugal casting. One of its primary advantages is that, thanks in part to the increased pressure applied to the melting metal during mould filling and in part to the shorter filling time that minimizes the transfer of heat due to the hot metal to the mould, centrifugal force allows for the production of thinner wall castings than is feasible with traditional static casting. Because of the improved contact with the mould, the pressure applied to the molten metal might shorten the time it takes to solidify and aid in feeding

Solidification rate in vertical centrifugal casting is majorly influenced by inherent vibration and fluid dynamics of the process and not by centrifugal pressure (F.S. Slivia.et.al. 2009).

S.C. Mondal mentioned in his paper that the quality of the casted product depends on the rate of solidification, poring time, poring temperature, pre-heating temperature and the RPM of the mold. (2010).

Inner defects of casting decreases with increase in rotational radius and rotational velocity (Li. Changyun.et.al 2010).

When we decrease the pouring temperature, the mechanical properties increases due to fine grains in matrix formed during the process. P. Shailesh found that increase in die-speed increases ultimate tensile strength due to effect of centrifugal force acting on the metal. (2012).

The casting parameter which influences the solidification structures includes the mold rotational speed, mold dimension, pre-heating temperature of the mold, pouring temperature and metal comparison. (Narendranath.et.al 2012).

2.3. CFD

The analysis of fluid flow, heat transport, and related phenomena like phase change in systems by computer-based simulation is known as computational fluid dynamics, or CFD. Using a collection of mathematical formulas that characterise the flow, a numerical representation is initially built. The motion of variables across the flow domain are then obtained by solving these equations with the aid of a computer programme. CFD has been studied extensively and used broadly to many elements of fluid dynamics since the invention of the digital computer. CFD is now a potent instrument for the design as well as evaluation of engineering processes, among other processes, thanks to its significant rise in both development and use.

2.4. Pre-processing

This is the initial stage of modeling, the 2D axis-symmetric cylindrical mold for centrifugal casting is developed using design modular of the ANSYS 15.3 software. After that the model is discretized into smaller domain by mesh module.

Next step after meshing the model is simulated using the FLUENT solver in ANSYS 15.3. The different controlling parameters are

- Speed of rotation
- Pouring temperature
- Pouring speed
- Mold temperature

Pre-processing steps are

- Creating geometry.
- Generating mesh.
- Set up and solver setting.

The dimension of geometry is

- INLET DIAMETER (in cm's) 1.05
- HEIGHT OF CYLINDER(in cm's) 11.1
- WIDTH OF CYLINDER(in cm's) 4.00

For solving set of equations, CFD used numerical technique in order to do such we need to discretize the variables for that we need to create mesh. The mesh quality can be checked by:

- Skewness.
- Aspect ratio.
- Element quality.

2.5. Set up and solver setting

The next step after meshing, we export the model to FLUENT software there we check the mesh quality; if error is not found we add general setting, material and appropriate boundary conditions. We perform patching and initialization for getting solution.

The outline followed for solving CFD simulation of vertical centrifugal casting problem is:

- Geometry modeling.
- Mesh generation.
- Model setup.
- Defining material properties and boundary conditions.
- Numerical simulation and results.

2.5.1. Assumptions

- Axis-symmetric model.
- Fluid followed Newton's law.
- We consider conduction and convection mode of heat transfer.
- Mold expansion is negligible.
- No presence of air gap between molten metal and mold
- No oxides and impurities.

2.6. Geometry and Mesh specification

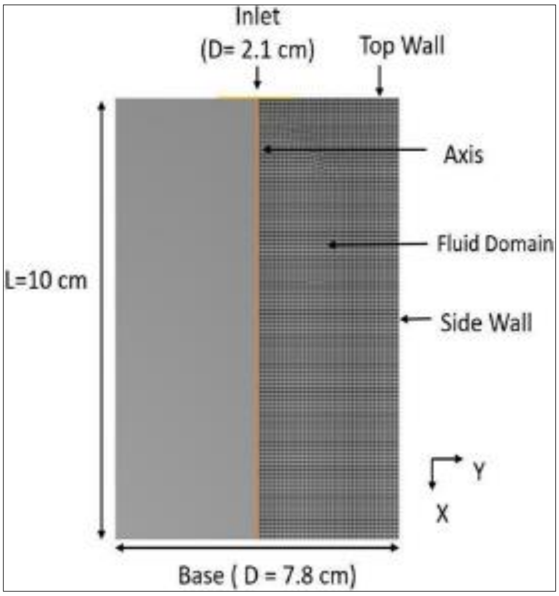

Figure 1 Geometry and mesh of geometry

Table 1 Mesh specification of geometry

Criteria	Specifications
Mesh Type	Quad. Mesh
Element size	10-3 m
Minimum edge length	1.05e-002
No. of elements	4460
No. of nodes	4612
Minimum Orthogonal Quality	9.99993e-01
Maximum Ortho Skew	6.58070e-06
Maximum Aspect Ratio	1.75061e+00

2.6.1. Models used in simulation

- Enthalpy-porosity model
- Solidification-melting model
- K-epsilon model
- VOF model

Enthalpy-porosity model: FLUENT used enthalpy porosity model is used to solve fluid flow problem involving solidification-melting model, here we treat liquid-solid mushy zone as a porous zone here melt interface is not tracked explicitly. Here we use a quality called liquid fraction which indicates the fraction of cell volume, at end of each iteration we complete liquid fraction. The mushy zone region lies between 0 and 1.

Solidification-melting model: We use FLUENT to simulate solidification-melting model, it's explicitly track the porous zone. We use a set of equations to solve the model. Some set of equation used are: energy equation, momentum equation. The governing equation used in CFD is Navier- Stokes equations. The Navier- Stokes consists of conservation of mass, momentum, energy.

K-epsilon model: It is a semi-empirical model used to simulate turbulent flows with k and ε variables. Near wall treatment was set to standard wall function treatment during simulation.

2.7. Selection of material

Aluminum was selected for the casting metal due to its wide scale industrial use. Also, Aluminum has lowest cost per unit volume; second lightest to magnesium; highest rigidity; good machinability, electrical conductivity, and heat-transfer characteristics.

Table 2 Properties of aluminum

Properties of Aluminium	Value
Density (Kg/m3)	2720
Specific Heat Capacity (J/Kg- K)	963
Thermal Conductivity (W/m- K)	170
Viscosity (Kg/m-s)	0.0014
Standard State Enthalpy (J/Kmol)	3.28e+08
Reference Temperature (K)	300
Pure Solvent Melting Heat (J/Kg)	400000
Mol. Wt. (Kg/Kmol)	26.891
Solidus Temperature (K)	865
Liquidus Temperature (K)	930
Properties of Mild steel mold	Value
Density (Kg/m3)	7850
Specific Heat Capacity (J/Kg-K)	510
Thermal Conductivity (W/m-k)	54

2.7.1. Boundary condition

- Mold wall: rotating wall.
- Axis-symmetric model is turned on.
- Convective heat transfers at outer surface of mold.
- 0.36 kg of Aluminum is poured into the mold.
- During case 2 rotational speeds is kept at 1432 rpm during pouring stage and 4774 rpm during solidification stage.

Table 3 Governing parameters of case 1 &2

Parameters	Case 1	Case 2
Pouring velocity(m/s)	0.5	0.8
Inlet Temperature(K)	938	938
Mold rpm	2845	1432 to 4774
Wall Thickness(m)	0.001	0.001
Preheating Temperature(K)	450	773
Free stream Temperature(K)	298	298
Heat Transfer Coefficient(W/m2-k)	100	100
Contact Resistance(m2-k/W)	0.001	0.001

Solution method

- Pressure- Velocity coupling.
- Scheme: Simple.
- Gradient: Least square cell based.
- Pressure: PRESTO!
- Momentum: Second order upwind.
- Swirl velocity: Second order upwind.
- Volume fraction: Geo-Reconstruct.

Initialization of solution:

- Type: Hybrid Initialization
- Equations are solved until we get a converged solution.
- Temperature patching is done to set pre-heating temperature of mold.
- Phase patching is done to set zero initial volume fractions.

We are considering two cases for simulation and use different boundary conditions for them. Different contours used are:

- Volume fraction contour.
- Solidification melting contour.

Volume fraction contour:

- Blue phase: Air phase.
- Red phase: Aluminum phase

Solidification melting contour:

- Red region: Air phase.
- Deep blue: Solidified aluminum.
- In between colors: Mushy zone

2.8. Contour of case-1

- Molten aluminum was made to strike mold directly.
- It rises upwards due to centrifugal force.
- After 0.36kg of aluminum was filled pouring was stopped.
- Solidification started from the topmost and bottom most corner
- Then it progressed towards the Centre bore.
- We get a cylinder with a central bore and a close end at the bottom.
- Improper thermal boundary conditions at mold wall and lesser mold rotational speed.
- Molten phase is partially in liquid phase in central bore
- Due to improper thermal boundary conditions solidification of molten metal ceased at a certain distance from mold wall.
- A layer of molten metal starts flowing down due to insufficient centrifugal force and it accumulates at the bottom of mold and solidifies at the bottom.

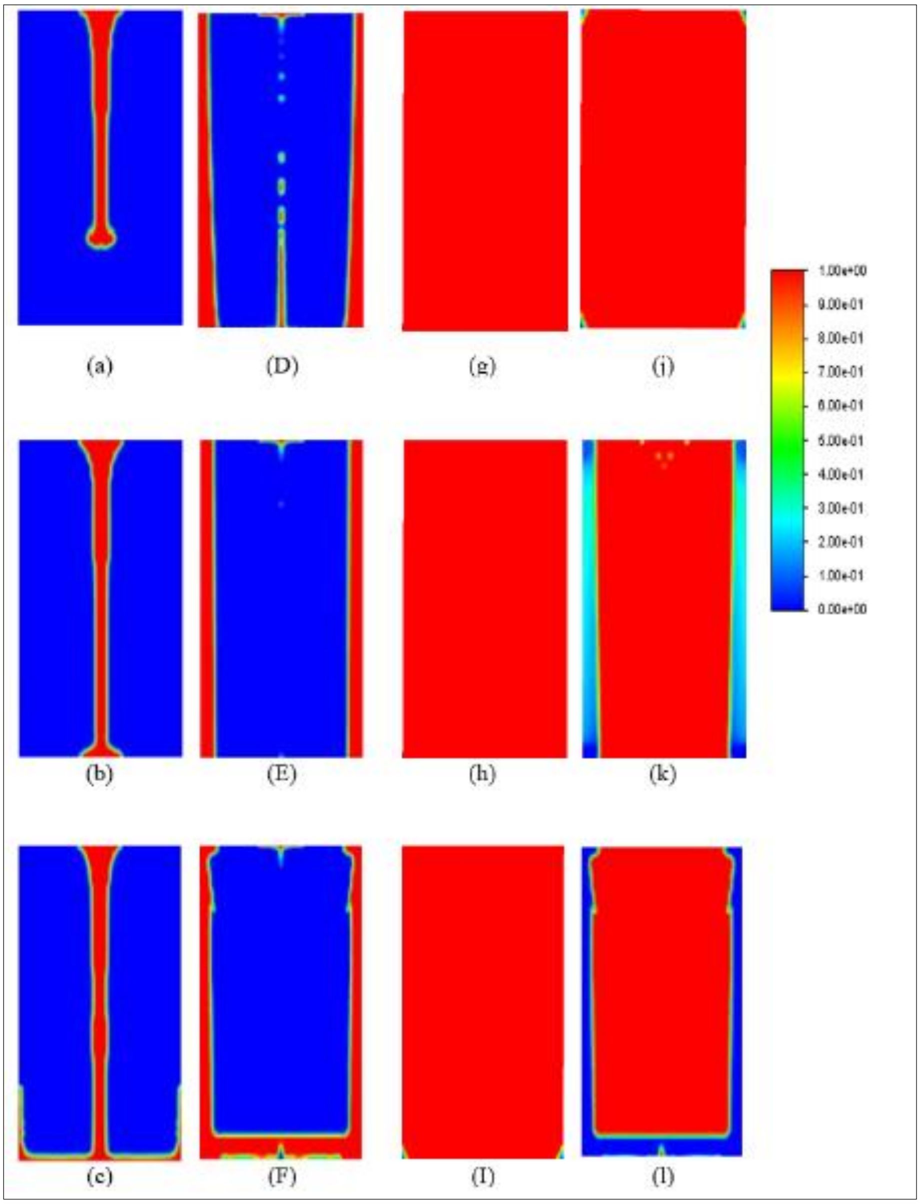

Figure 2 Phase contours (on left) along with their Melt fraction contours (on right) for Case 1at(a), (g)0.16s; (b),(h)0.18s; (c),(I) 0.32 s;(d),(j)1.53s; (e), (k)1.93s; (f),(l)5.93s

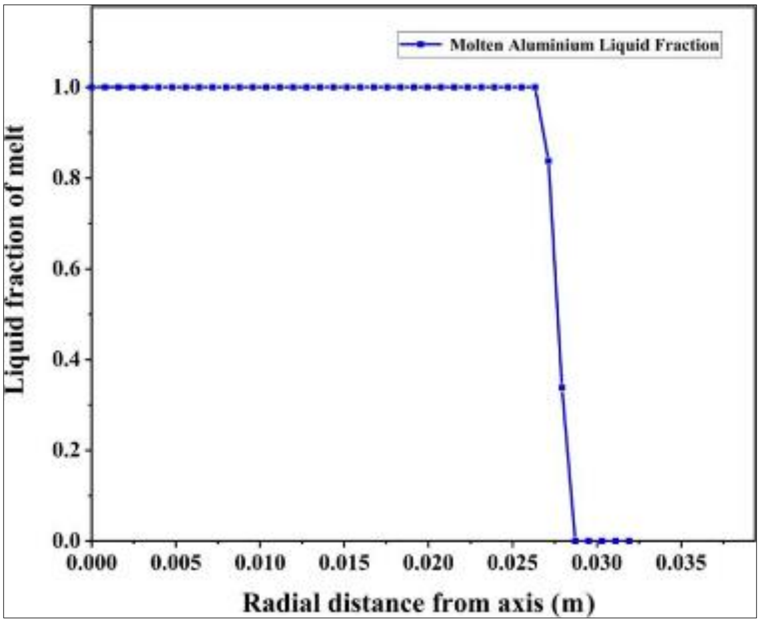

Figure 3 Plot of molten Aluminium volume fraction at the top and bottom portions of mold against radial distance from axis

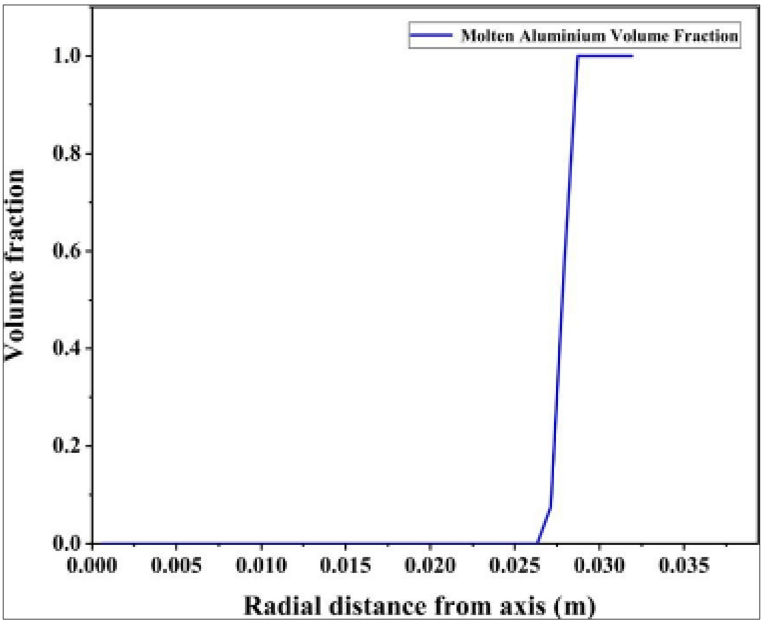

Figure 4 Plot of molten Aluminium liquid fraction at the top and bottom portions of mold against radial distance from axis

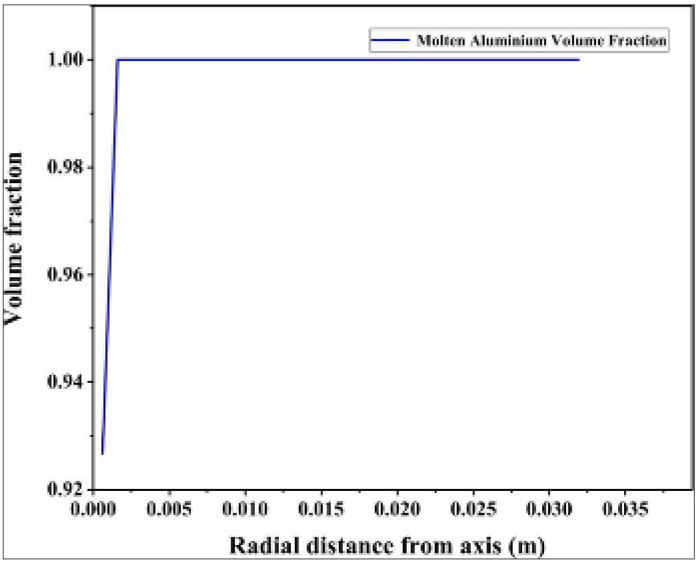

Figure 5 Plot volume fraction of aluminium (at the bottom of the mold) against radial distance from the axis of rotationforCase1

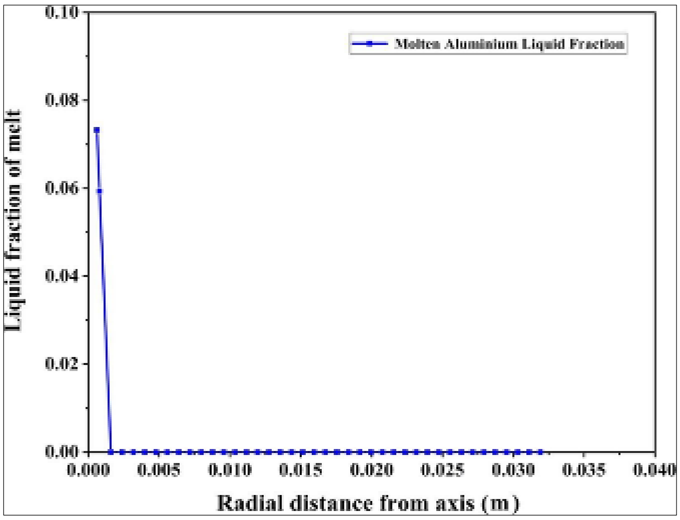

Figure 6 Plot of liquid melt fraction of aluminium melt (at the bottom of the mold)against radial distance from the axis of rotationCase1

The above shows that the thickness of the casted cylinder at the top is 1.3 cm approx. This value is well within experimental values of 1 cm at the top and 1.4 cm at the bottom.

2.9. Contours of case-2

- Molten aluminum was made to strike the walls of the mold.
- A cylinder with parabolic bore was obtained.

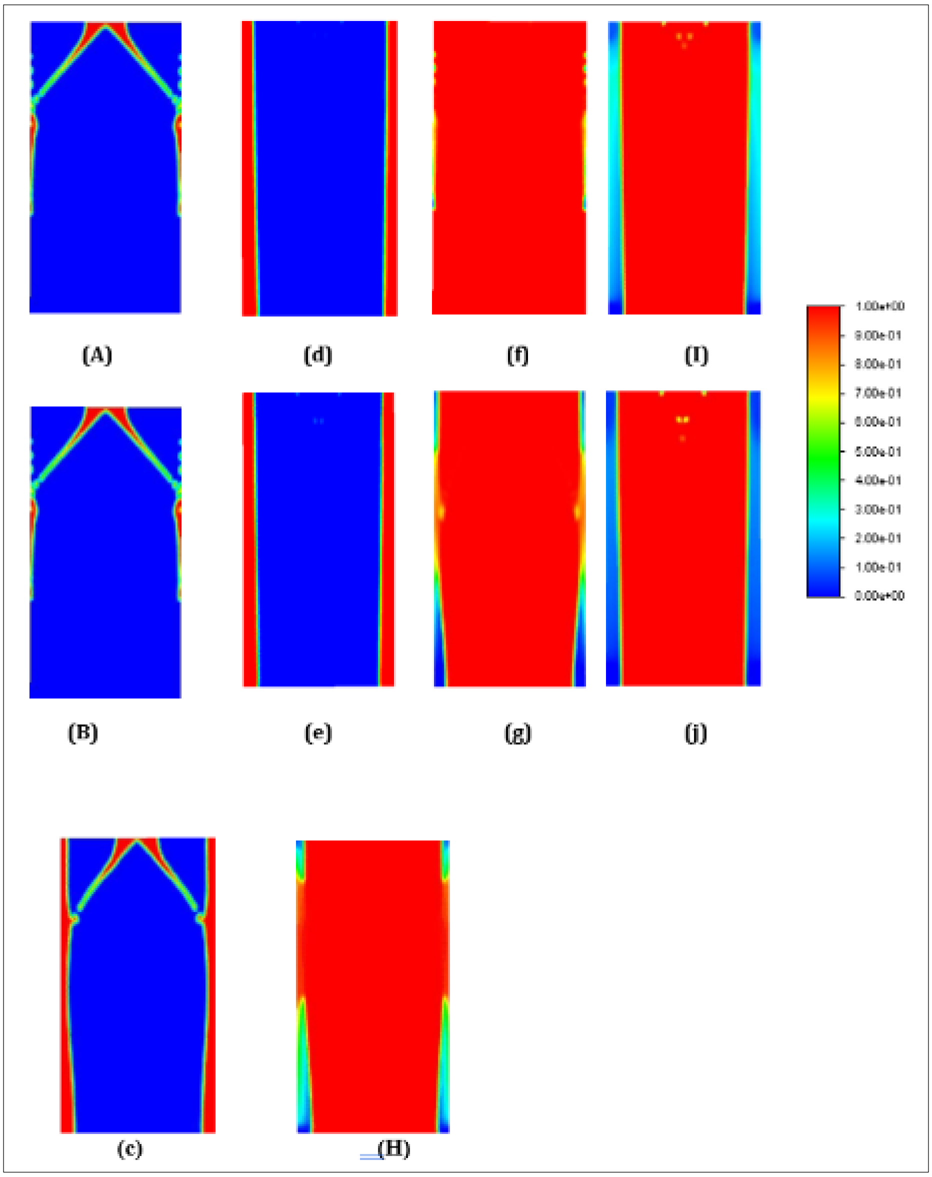

Figure 7 Phase contours (on left) along with their Melt fraction contours (on right) for Case 2 at (a), (f) 0.12 s; (b), (g) 0.15s; (c), (h) 0.31 s;(d), (I) 1.47 s; (e), (j) 1.83 s

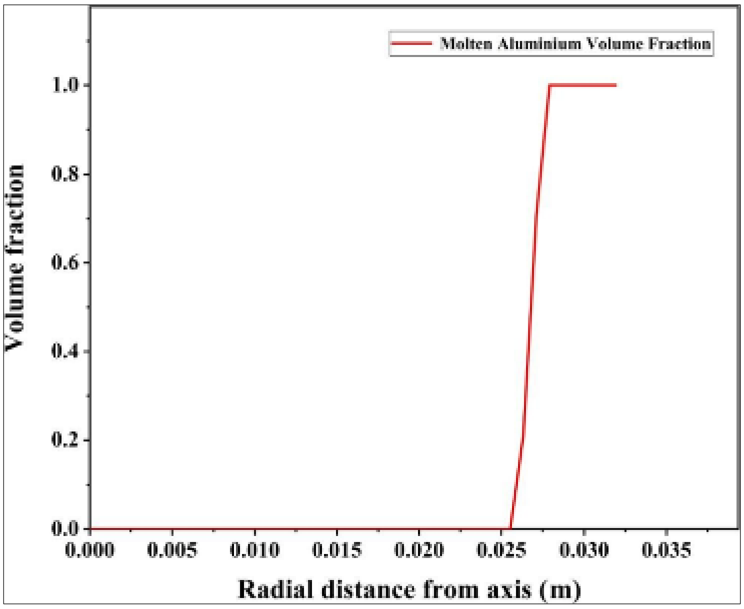

Figure 8 Plot of volume fraction of aluminium (near the top of the mold)against radial distance from the axis of rotation for Case2

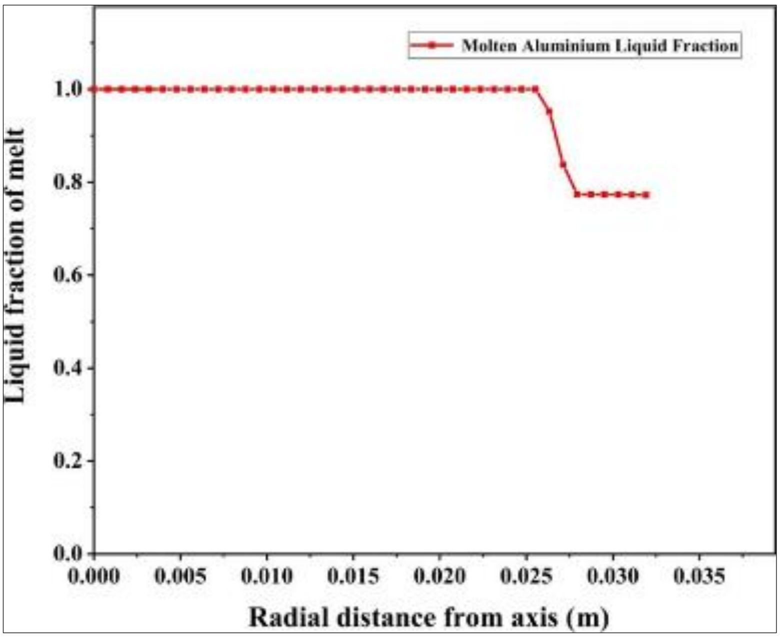

Figure 9 Plot of liquid fraction of aluminium melt (near the top of the mold) against radial distance from the axis for Case2

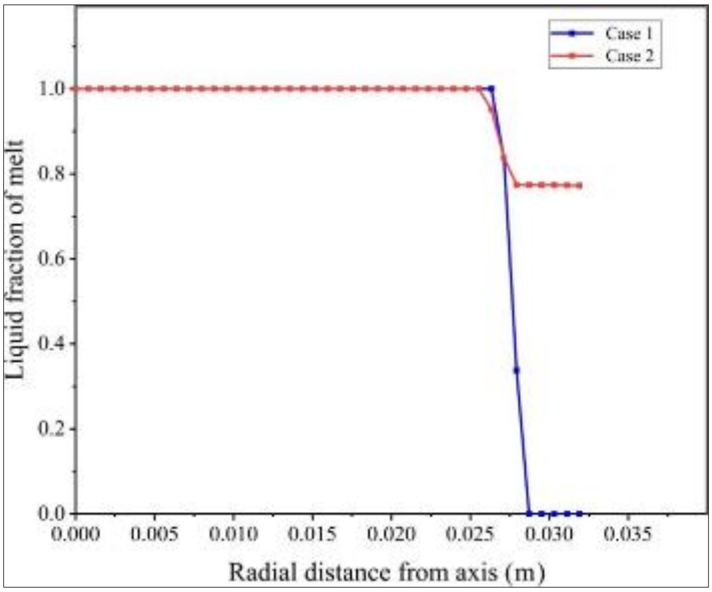

Figure 10 Plot comparing liquid fractions of aluminium melts for Case 1 and Case 2againstradial distance from the axis of rotation

The above showthatthethicknessofthecastedcylinderattopis1.4cmapprox.Thisvalueiswithin experimental values of thickness 1 cm at top and 1.4 cm at the bottom**.**

Region of plot where the liquid fraction of melt is one indicates presence of air at that location, where it is zero, indicates presence of solidified aluminum phase values in between indicate semi solid region.

Table 4 Comparison of simulated value with experimental value

COMPARISON WITH EXPERIMENTAL VALUES			
Variables	**Simulation Values**	**Changes**	**Experimental data**
Inlet velocity	0.5m/s	1 m/s with only air entering during solidification phase.	----
Inlet temperature	938 k (665 deg C) during pouring	300 k (during solidification)	660.3 deg. C (melting point of aluminium)
Convection coefficient	50 W/m²k (during filling) 100 W/m²k (during solidification)	0-1000 W/m² k	50 W/m² k
Free stream Temperature	298 k	298 k- 600 k	298 k
Mould Rpm	4774 rpm	1432 to 4774 rpm	1980 rpm

3. Conclusion

- Inlet velocity: It changes to 1m/s with only air entering through inlet during solidification phase. It increases with decrease in filling time.
- Convective wall thickness: When we decrease the value molten al start to fall down during solidification. On increasing the value molten al stops sliding along the walls.
- Free stream temperature: When we decrease its value, molten al start to fall during solidification, on another hand on increasing the value, molten al stops sliding down along the walls.
- Mold RPM: When we keep the value 1432 then we find that the tapering has increased and the glass shape is observed after solidification. While when we keep the value as 4774 very slight degree of taper was observed.
- Time step size: When we keep the time step as 1e-03 the solution does not converge and when we keep the value 1e-05 the solution converges.

Future scope

- The present model has been developed for only one dimension (radial direction), but since longitudinal temperature distribution also has significant effect on the mechanical properties of centrifugal casting, so for more realistic simulation above developed model should be solved in two dimensions.
- In the present model the heat transfer due to conduction in various regions is only considered, the consideration of convective heat transfer in liquid region can significantly increase the accuracy of results.
- Such a transient heat transfer model can also be exploited further to predict the time-temperature information which if correlated with the time-temperature transformation diagram of a specific alloy system may lead to significant information about the microstructure of the developed casting

References

[1] Basu, B., and Date, A.W., Numerical Modelling of Melting and Solidification Problems-A Review,*Sadhana*, *Indian Academy of Science*, Vol-13, Part-3, pp 169-213, 1988.

[2] Bonacina, C., Comini, G., Fasano, A., and Primicerio, M., Numerical Simulation of Phase Change Problems, *International Journal of Heat and Mass Transfer*, 16, pp1825-1832, 1973.

[3] Choi, S.H., Kang, C.S. and Loper, C. R., A study of the bonding of stainless steel to cast iron in centrifugalcasting, *AFS Transactions*, pp 971-981, 1989.

[4] Crank, J., and Crowley, A.B., Isotherm Migration along Orthogonal Flow Lines in Two dimensions,*International Journal of Heat and Mass Transfer*, Vol-21, pp 393-398, 1978.

[5] Crank, J., and Gupta, R.S., Isotherm Migration Method in Two dimensions, *International Journal of Heatand Mass Transfer*, Vol-18, pp 1101-1107, 1975.

[6] Crowley, A. B., Numerical Solution to Stefan Problems, *International Journal of Heat and Mass Transfer*,21(2), pp 215-219, 1978.

[7] Cumberland, J., Centrifugal Casting Techniques, *The British Foundry man*, pp 26-46, 1963

[8] Ebisu, Y., Computer simulation on Macrostructure in Centrifugal Castings, *AFS Transactions*, pp 643-655,1977.

[9] Gao, J. W. and Wang, C. Y., Modelling the Solidification of Functionally Graded Materials by CentrifugalCasting, *Material Science and Engineering*, A292, pp 207-215, 2000.

[10] Gupta, R.S., and Kumar, D., Variable Time Step Methods for One Dimensional Stefan Problem with MixedBoundary Condition, *International Journal of Heat and Mass Transfer*, Vol-24, pp 251-259, 1981.

[11] Hiene, R.W., and Rosenthal, P.C., Principle of Metal Casting, *McGraw-Hill*, *New York*, 1955.

[12] Shamsunder, N., and Sparrow, E. M., Analysis of Multi-Dimensional Conduction Phase Change viaEnthalpy Model, *Journal of Heat Transfer*, Vol-97, pp 333-340,1975.

[13] Sparrow, E.M., Ramadhyani, S., and Pathankar, S.V., Effect of Sub-Cooling on Cylindrical Melting,*ASME, Journal of Heat Transfer*, Vol-100, No.2, pp 395-402, 1978.

[14] Szekeley, J., and Themlis, N.J., Rate Phenomena in Process Metallurgy, *Wiley Interscience*, New York,19

[15] Upadhya, G., and Paul, A.J., Solidification Modelling: A Phenomenological Review, *AFS Transactions*,pp 75-80, 1994.

[16] Yang, B.J., Liu, W. T. and Su, J. U., Numerical Simulation and Experimental Investigation of thesolidification of Centrifugally Cast Cylinder Sleeves, *AFS Transactions*, pp 763-768, 1994.

[17] Madhusudhan, Narendranath S, G C Mohan Kumar, Properties of Centrifugal Casting at DifferentRotational Speeds of the Die, Volume 3, Issue 1, January 2013), Website: www.ijetae.com (ISSN 2250-2459).

[18] F.S. Silva.el.al, On assessment of processing variables in vertical centrifugal casting technique, International Journal of cast metals research Volume 22, Issue 5

[19] Li. Changyun.el.al, Research on mould filling and solidification of Titanium Alloy in vertical centrifugalcasting, Rare Metals Materials and Engineering Volume 39.

[20] S.K. Jha et.al. Effect of mould rotational speed on the quality of bimetallic pipe fabrication by centrifugalcasting process, International Journal of emerging research in management and technology Volume 6, Issue 7

[21] C.E. Etin Osa et.al, Temperature distribution in centrifugal casting with partial solidification during process, International Journal of materials and engineering technology Volume 2, Issue 2.