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Analysis Casting Simulation and Its Importance

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Abstract: Casting as a manufacturing process to make complex shapes of different materials in mass production may experience many different defects such as shrinkage porosity, sink, cavity and incomplete filling. For new castings or the castings having very high rejection rates, modification of feeding system design is of prime importance. A well designed feeding system is very important to ensure the better quality of castings. Design of feeding system also involves the decision about correct location of risers and number of risers to be used. Generally, gating system controls the velocity of molten metal that affects turbulence and flowability of casting. Solidification of metals stands as marvel of ultimate significance for metallurgists, casting engineers and physicist which hampers the quality of castings, material yield and cycle time. Casting defects are decreased through casting simulation software and an intellectual feeding technique.
AUTO Cast (Demo) is casting simulation software which can simulate thermal changes and heat transfer in the solidification process of a casting. It assists the user to visualize the solidification process of a particular casting. The simulation software offers functions to help guide a user in producing gating and riser designs and also have functions which produce visual outputs showing possible problem areas and defects which may occur in a casting. It can help shorten the lead time and reduce the loss in the trial casting stage. Having demo version of AUTO Cast we have limited by designed gating system for cube. In present paper, an attempt is made to design the gating system with calculations and simulate solidification processes of the casting with the ANSYS.

Keywords—Runner, Riser, Sprue , Sprue base, Gating System,Simulation

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I. INTRODUCTION

Sand casting consists of placing a pattern (having the shape of the desired casting) in sand to make an imprint, incorporating a gating system, filling the resulting cavity with molten metal, allowing the metal to cool until it solidifies. Sand casting is still the most popular form of casting.

SAND CASTING PROCESS DESIGN

The typical sand casting process design consists of the following steps.
1) Sand Selection
2).Parting line
3).Pattern design
4).Core design
5).Gating/riser system design

CASTING SIMULATION SOFTWARE

Usefulness:
Defects and problems can be discovered before the actual casting is cast avoiding costly tests to prevent the problems

Limitations

Casting simulation software cannot predict all types of defects that may occur in a casting, such as processing defects, human error, and additional chemical elements added to the molten metal, etc.

ANSYS

Solidification and cooling of a classically casting and the simultaneous heating of the mold is, from the viewpoint of thermo kinetics, a case of two dimensional (2D) transient heat and mass transfer in a system comprising the casting, mold and ambient. If mass transfer is neglected and – from the three basic types of heat transfer – conduction is considered as the decisive, then the problem can be reduced to the solving of the Fourier equation. Here, the used 2D model of the temperature field of the system is based on the numerical finite-element method.

II. MODELING AND SIMULATION

Dimension of Pattern
Area of the outer rim:

Outer diameter $A1=\frac{\pi d^2}{4}=\frac{\pi ¿4^2}{4}=12.56$ *cm^2*

Inner diameter $A2=\frac{\pi d^2}{4}=\frac{\pi ¿3^2}{4}=7.0685$ cm^2

Total area of rim A= A1-A2= 5.4975 cm^2
Volume of rim: V1= A*h = 5.4975*6= 32.985 cm^3

Area of the inner rim:

Outer diameter $A3=\frac{\pi d^2}{4}=\frac{\pi ¿3^2}{4}=7.0685$ *cm^2*

Inner diameter $A4=\frac{\pi d^2}{4}=\frac{\pi ¿1^2}{4}=0.7853\,cm^2$

Total area of inner rim A= A3-A4 = 6.2831 cm^2
Volume of inner rim V2= A*h = 6.2831*3 = 18.8493 cm^3
Total volume of rim V = V1+V2 = 32.985+18.8493 = 51.8433 cm^3

Shrinkage of the Aluminum is added to casting
For aluminum, solidification shrinkage = 6.6%, solid contraction during cooling = 5.6%.
Total volumetric contraction = (1-0.066)(1-0.056) = 0.8817
Linear contraction = $(0.8817)^{0.333}$ = 0.9589
Final casting dimensions

Oversize factor for mold = $(0.9589)^{-1}$ = 1.0428
Mold cavity dimensions: *D* = 4 .00(1.0428) = 4.1714 cm
Thickness t = 3(1.0428) = 3.128 cm

Core Design & Core Buoyancy Force:
Core volume & weight:
ρ*core*= 1600 kg/m^3
Self-weight of large hole, *WB1= π d^2* l *ρcore*9.81 / 4 = π *3^2*1.5*1600*(10^-6)*9.81/ 4*
= 1.6642 N
Self-weight of small hole, *WB2= π d^2* l *ρcore*9.81 / 4= π *1^2*3*1600*(10^-6)*9.81/ 4*
= 0.3698 N
Total self-weight of core, *WB=WB1 + WB2*
= 2*166.42+36.98
=0.36982 N
The buoyancy force *B* on the core *B = π d^2* l*ρmetal/ 4*
= π (2*3^2* *1.5+1^2*3)**2700*9.81*(10^-6)/ 4*
=0.624085 N
The net force on the core (upward) = *B* – *W*
= 0.254265 N

Mold size:
Volume of casting= 51.8433 cm^3
60% of yield = 51.8433/.6 = 86.4055 cm^3
Weight of metal poured per mold = 60% of yield * Density of Aluminum
=0.2332 kg

Properties of Aluminum

Pouring Temperature (Tp)	Solidus Temperature (Ts)	Interface Temperature	Specific Heat (C)	Latent Heat J/ kg	Density (ρ) Kg/m^3

oC	oC	(Tint) oC	J kg-1 oC-1		
730	590	531	910	397*10^3	2700

Table 3.1 Properties of Aluminum

Solidification time: (*Assume Tint = 0.9 x Ts*) *Tint = 09* 590 = 531*

Properties of Sand

Thermal Conductivity (K) W/m/k	Specific Heat (C) J kg-1 oC-1	Density (ρ) Kg/m^3
0.61	1130	1600

Table 3.2 Properties of sand

Solidification Time

Type	**Volume (cm^3)**	**Surface area (cm^2)**	**Modulus (V/A)**
A	32.985	18.85	1.749
B	18.843	18.849	0.9996

Table 3.3 Modulus ratio

$$\sqrt{\tau_s} = \frac{\rho_{cast}\left[L + C_{cast}\left(T_{pour} - T_{sol}\right)\right]}{1.128\sqrt{K_{mold} \times \rho_{mold} \times C_{mold}} \times \left(T_{int} - T_{amb}\right)} \times \left(\frac{V}{A}\right)$$

τS = 1814.76 sec
= 30.24 min
= 0.504 hr

Riser Design

Heat transfer criteria

MC: MN: MF = 1: 1.1: 1.2

Where MF, MC and MN are modulus of feeder, modulus of casting, and modulus of the neck of feeder atthe junction of casting respectively.

Let Df = Diameter of feeder
Hf = Height of feeder

Assume Hf/Df = 1.5

Modulus of feeder = 1.2* modulus of region around hot tear
= 1.2*1.75
= 2.1

Volume of feeder = *π Df* Hf /4+π Df^2/4*
= 1.75*π *Df^2*

Surface area of feeder = *π Df^2* Hf /4*
= 0.375*π *Df^3*

Modulus (V/A) = 0.214*Df
i.e 2.1 = 0.214*Df
Df = 0.9813 cm
Hf = 1.472 cm

Volume of hot spot region = 33 cm^3

Modified surface area of last freezing region
= surface area of hot spot – area of feeder bottom
= 4.744 cm^2

Modified last freezing region = 5.5/4.744
= 1.159

Modified modulus of feeder = 1.2*1.159 = 1.3908 = 0.214*Df
Df = 6.49 cm
Hf = 9.74 cm

Modulus of neck, Mn = 1.1*1.159 = 1.275
Neck height = 1 cm
Neck diameter = Dn
Volume of neck = *π Dn^2*Hn/4*
Surface area = π Dn*Hn

Modulus, Mn = Dn/4 = 1.275
Neck diameter, Dn = 5.1

Feeder Yield and Efficiency

The riser efficiency depends on the feeder shape, type (open or blind) andapplication feed-aids, such as insulators or exothermic sleeves. It has to be consideredbecause the riser itself is also solidifying as it is feeding liquid metal to the casting. Foran open riser with a height per diameter ratio of 1.5, the efficiency is around 14 percent.It can be increased to about 50 percent if insulated with sleeves or exothermic sleeves.

Vol of casting, Vc = 51.84 cm^3
Vol of feeder, Vf = *π Df^2*Hf/4 + π Dn^2*Hn/4*
= 34.263 cm^3
Feeder Yield = Vc / (Vc+Vf)
= 60.21 %
Shrinkage allowance, α = 3.16% = 0.0316
Feeder Efficiency = α *(Vc+Vf) /Vf
= 7.94%
Modulus of feeder insulated sleeve with modulus extension factor = 1.4
Modulus of insulated feeder = 1.2*1.159/1.4
= 0.9943
Modulus of feeder, Mf = 0.214*Df
Diameter of feeder, Df = 4.64 cm
Height of feeder, Hf = 6.96 cm

Optimal Filling Time

A casting that fills too slow can have discontinuities such as cold shuts and misruns. Too fast filling can lead to solid and gaseous inclusions.

A generalized equation for filling time can be written as:

Tf = K0 (Kf* Lf / 1000) (Ks + Kt t / 20) (Kw W)^p

There are five coefficients: *K0* is an overall coefficient, and *Kf, Ks , Kt, Kw* are thecoefficients for fluidity, size, thickness and weight, respectively. For Aluminum thefollowing values may be used: *K0 = 1.0, Kf= 1.0, Ks = 1.1* (for castings of size 100-1000mm), *Kt= 1.4* (for wall thickness up to 10 mm), *Kw = 1* and *P = 0.4, Lf = 300 mm*.

Total Weight of the casting, W = (Wt of casting + Wt of feeder)/ 0.9
= 0.2583 Kg

Tf = 7.893 sec

Gating System

The main objective of a gating system is to lead clean molten metal poured from ladle tothe casting cavity, ensuring smooth, uniform and complete filling.

Sprue

It is circular in cross section. It leads the molten metal from the pouring basin to the sprue well. Assuming Characteristic Loss Coefficient = Cf = 0.8

Inlet velocity (at parting plane), Vs = Cf*□(2*g*H)
H = Mold height + Pouring height
= 14+6 = 20 cm
Vs = 1.584 m/sec

Gating ratio

It is given by *As:Ar:Ag* where *As* , *Ar* , *Ag* are the cross-sectional areas of sprue exit, runner(s) and ingate(s). If multiple runners and ingates are present, the totalarea (of all runners, or all ingates, respectively) must be considered. A converging diverging system, where the ingate area is more than the sprue exit area, is to bepreferred. This ensures that the metal slows down (thereby reducing turbulence-relatedproblems). Examples of such gating ratios include: 1:2:1.5 for ferrous and 1:4:4 for nonferrousmetals. Higher values of ingate area may be used (such as 1:4:8) to further reducethe velocity of molten metal through the ingates to within the recommended range, aslong as flow separation (and thereby air aspiration) is avoided.

Law of Continuity

The law of continuity states that the flow rate must be the same at agiven time in all portions of a fluid system. It may be written as:-

$Q = A1V1 = A2V2$

Where Q = metal flow rate in m^3/sec

A1 & A2 = cross-sectional area of flow channel at two differentpoints 1 & 2 in sq.cm

V1 & V2 = metal velocity at points 1 & 2 in m/sec.

As: Ar: Ag = 1:2:1.5

As*Vs = Ag*Vg

Velocity at ingate, Vg = 1.584/1.5

= 1.056 m/sec

Choke Area and Velocity

The choke is the smallest cross-section in thegating system that controls the flow rate of molten metal. The element (sprue exit,runners or ingates) with the smallest value in the gating ratio is considered the choke. Thechoke area *Ac* is given by:

Ac = W / (ρc* τf* Vc)

Where, *W* is the total casting weight (including feeders and gating channels), *ρc*is themetal density, τ*f* is the total filling time and *Vc*is the choke velocity.

Ac = 1.088 cm^2

The choke velocity is given by

Vc = Vp + cf √ (2 g H)

Vc = 1.584 cm/sec

Where*H* is the metallostatic pressure head, given by the vertical distance between theliquid level in pouring cup and the centerline of the choke. The value of pouring velocity*Vp*is non-zero, if poured from a height or if bottom pouring ladles are used. The frictionfactor *cf*within the gating system depends on its geometry and surface finish, and rangesbetween 0.6-0.9.

Gating Design-Sprue

Sprue top area, AST:

AST = (ASE x Vchoke)/ Vsprue top

AST = 1.884 cm^2

Sprue top diameter, DST:

AST = (π/4) x (DST)^2

DST = 15.5 mm

Sprue exit diameter, DSE:

ASE = (π/4) x (DSE)^2

DSE = 11.77 mm

Runner

The main function of the runner is to slow down the molten metal, which speedsup during its free fall through the sprue, and take it to all the ingates. Runner Design

Assume Runner having width/depth = 1.5,

Runner area (AR) = 2.176 cm^2

Runner Width = 12.04 mm

Runner Height = 18.06 mm

Ingate

The ingate leads the molten metal from the gating system to the mould cavity

Assume gate having width/depth = 2,

Gate area (AG) = 1.632 cm^2

Gate Depth = 18.06 mm

Gate Width = 9.03 mm

SIMULATION

Preprocessing

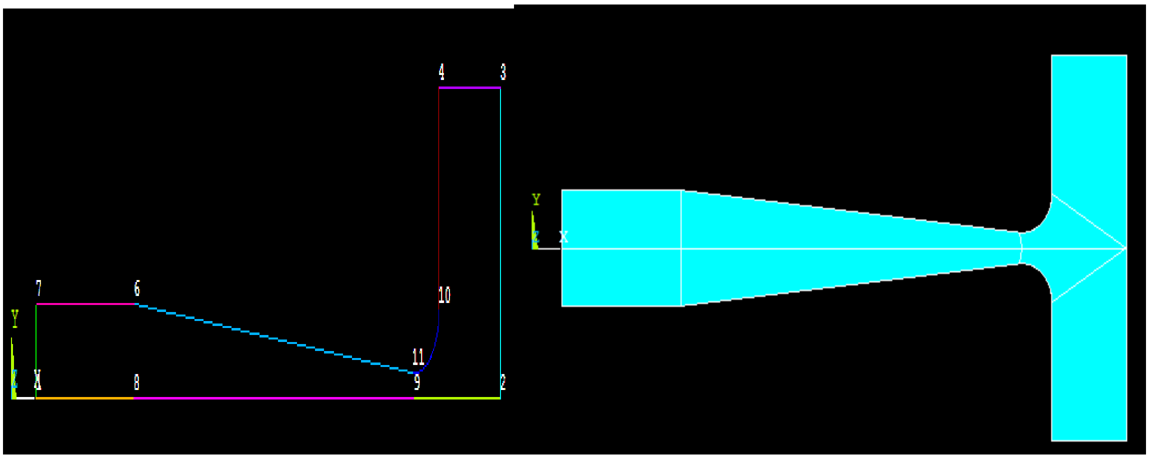
The preprocessing process contains the following commands to create a finite element model. They areas follows

1. Defining Element and Options
2. Defining Element Real constants

3. Defining Material Properties
4. Creating Model Geometries
5. Defining Meshing controls
6. Applying Boundary Conditions, loads

Model

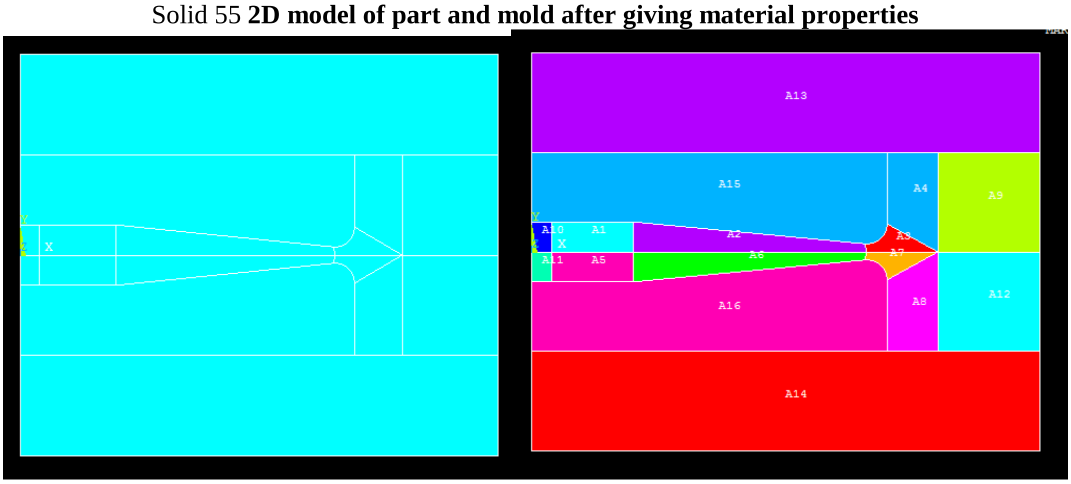
Once the model has been created and subjected to various boundary conditions ANSYS solves the set of equations generated by Finite Element Model.



2D model of casting part

Defining Element and Options

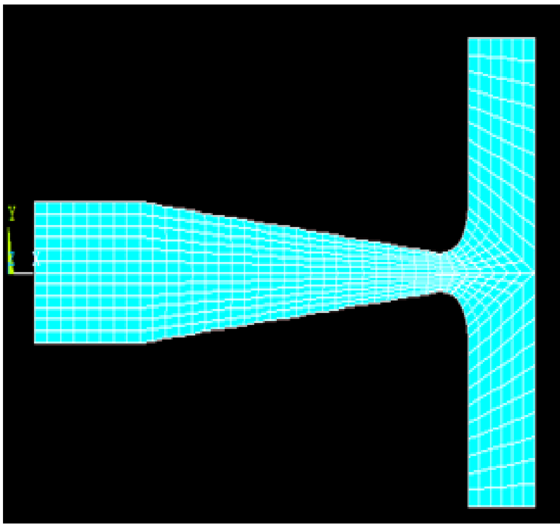
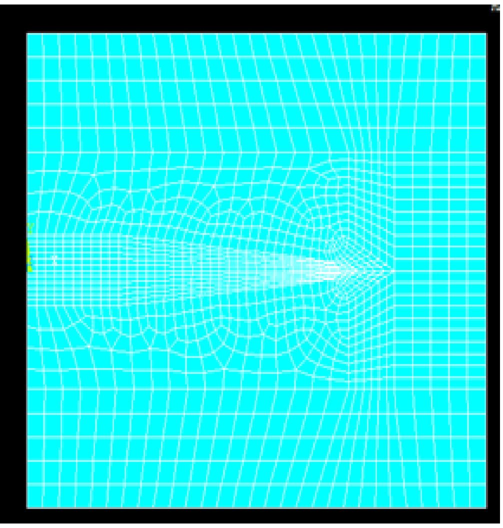
Solid 55 **2D model of part and mold after giving material properties**



Defining Material Properties

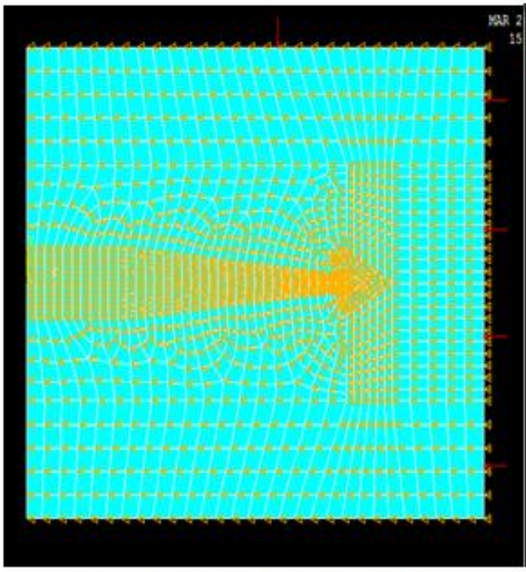
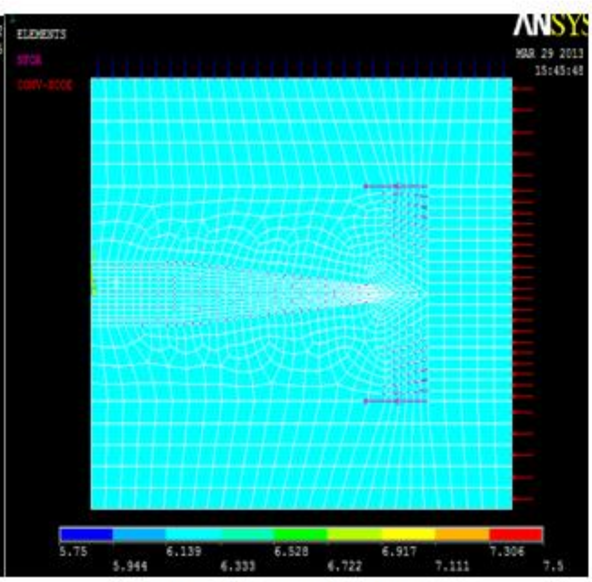
	Units	Sand	Al
Thermal Conduct.	(K) Wm-1 oC-1	0.346	94 (liq) 238 (solid)
Density	P g cm-3 (mg cm-3 oC-1)	2.32(bulk) 1.520 (Mold)	2.385 (liq) 2.7 (solid)
Specific Heat	(C) J kg-1 oC-1	1816	1050 (liquid) 896 (solid)
Heat of Fusion	(HF) J kg-1		395440
Melt Temp	(Tm) oC		696

Expansion Coeff.	(α) 10-6* oC-1	22.2	23.9

Meshing of casting part **Meshing of casting part with mold**

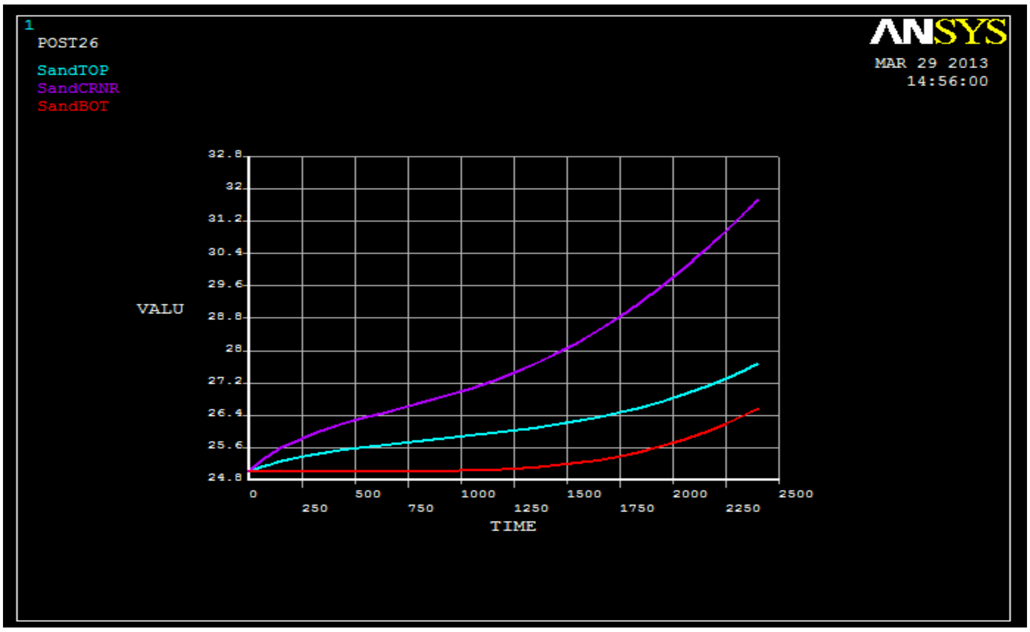
Applying Boundary Conditions, loads

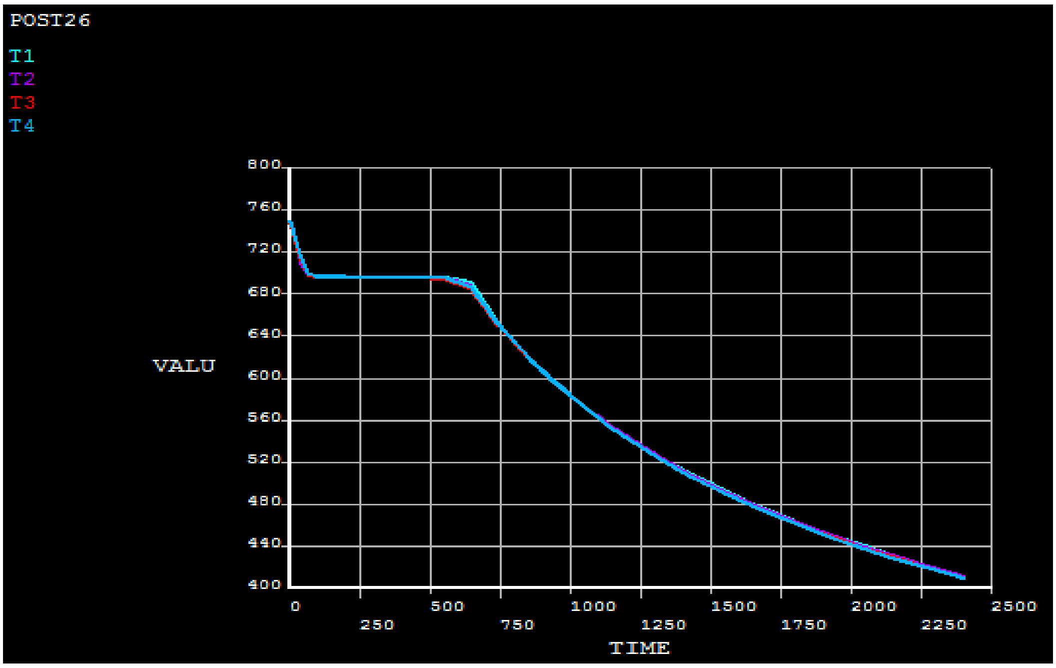
Applying conduction load **applying convection load**

III. ANSYS RESULTS

In this study, an analysis of heat transfer for the casting processin two dimensions was made for the nonlinear case. The idea was todetermine the distribution of temperature, heat flux, thermalgradient, cooling curves in the cast metal, and heating or/andcooling in the molds during casting process of pure Aluminum ingreensand and mold during 0.543 hours of solidification. Thephenomenon of convection that occurs between the mold and theenvironment was included in this study. In this case, the properties of the mold materials were considered as constant. However,enthalpy and thermo-physical property of pure Aluminum was consideredas a function of the temperature. The effect of radiation was ignoredhere Temperature distribution during solidification of casting to sand top, center and bottom w.r.t time



Temperature distribution during solidification of casting to sand top, center and bottom w.r.t time

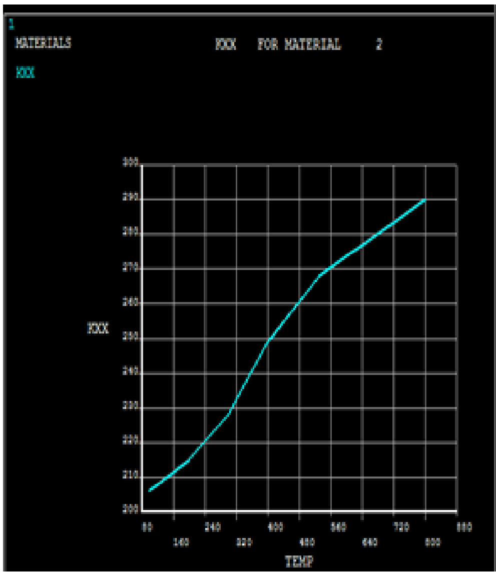


Heat loss from flywheel casting to surroundings w.r.t time

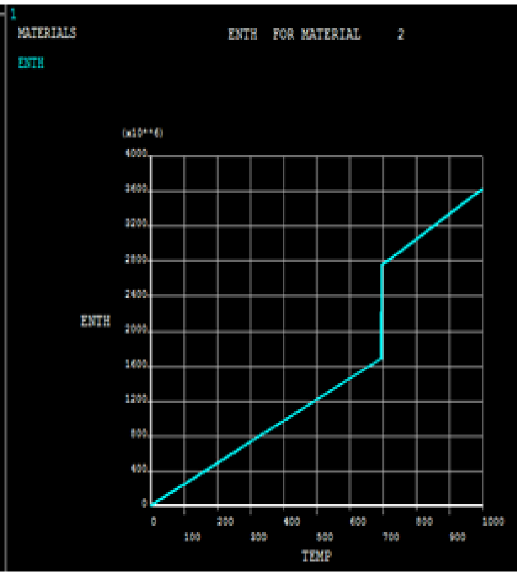
Plotting graph of Thermal conductivity versus Temperature of Aluminum

Temperature (℃)	0	100	200	300	400	530	800
Thermal conductivity (W/m-°C)	206	208	215	228	249	268	290

Table 3.8: Thermal conductivity of Al



Thermal conductivity Vs Temperature



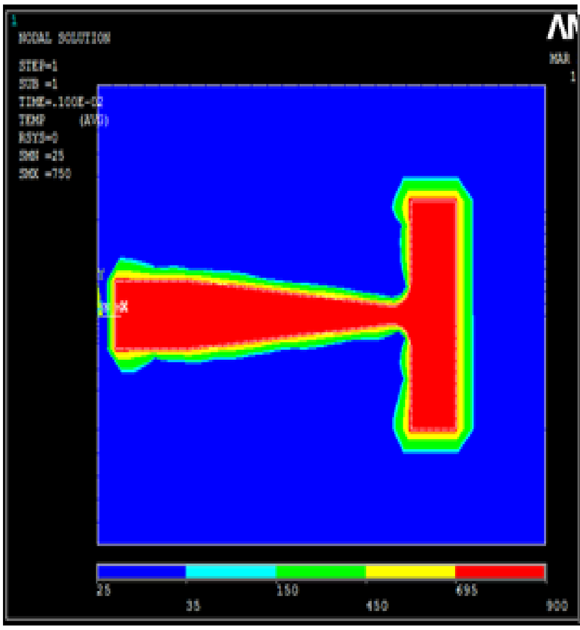
Enthalpy's Temperature

Plotting graph of Enthalpy versus Temperature of Aluminum

	H0	Hs	Hl	H
Temperature (℃)	0	695	697	1000
Enthalpy (J/m^3)	0	1.6857E9	2 7614E9	3.6226E9

HEAT FLOW IN FLYWHEEL DURING SOLIDIFICATION

The results can be represented as contour plot with temperature distribution at any node, or as paths between temperature and the time at any node in the body as shown in Fig.



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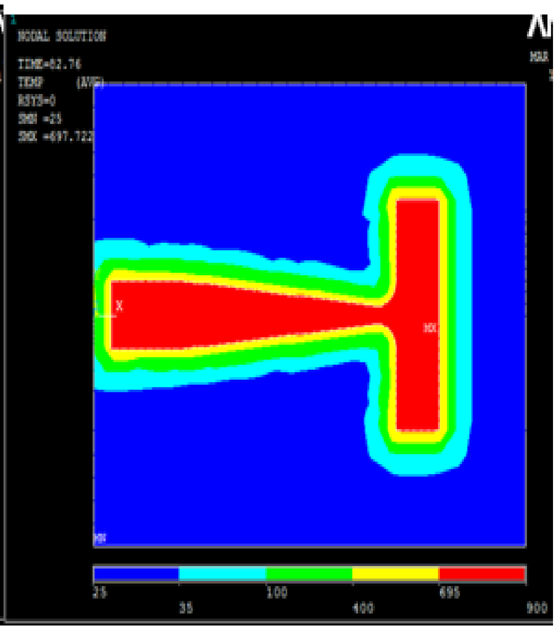

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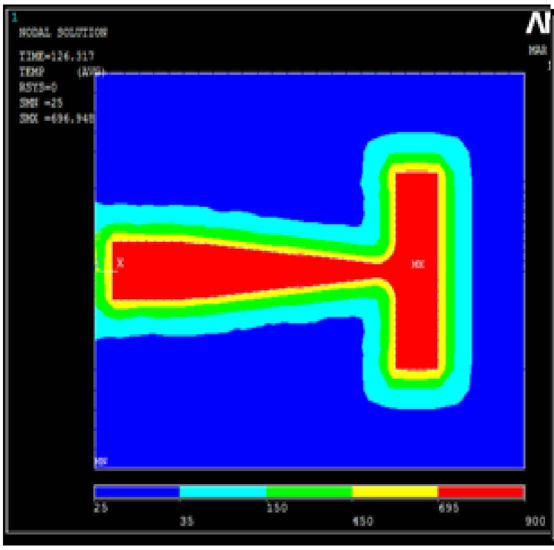

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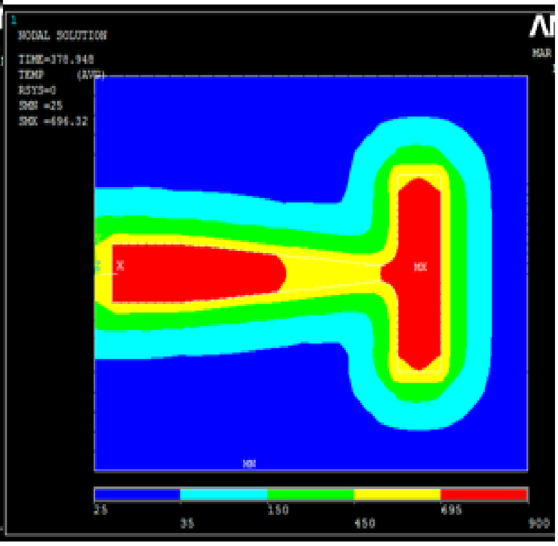

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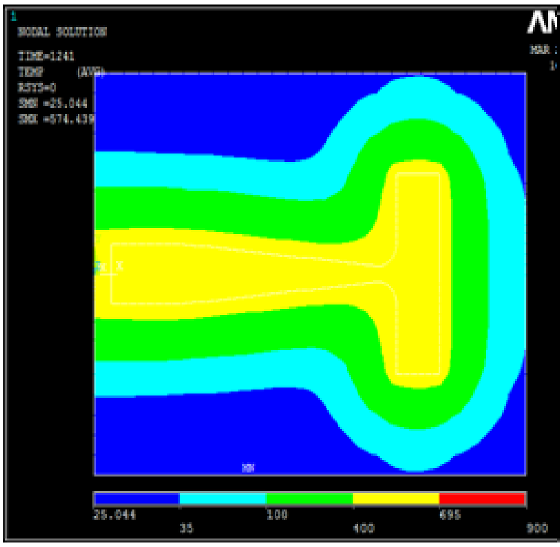

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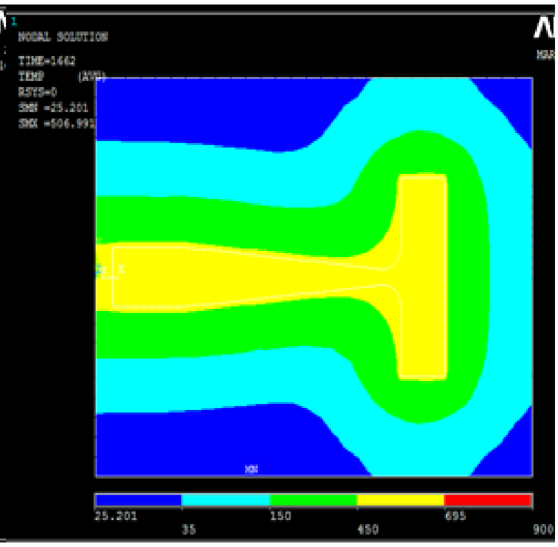

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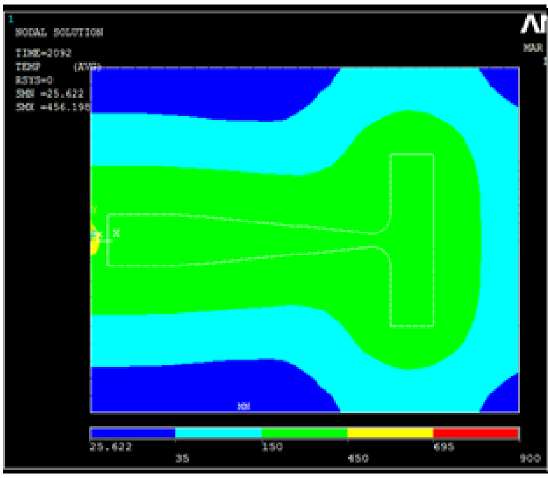

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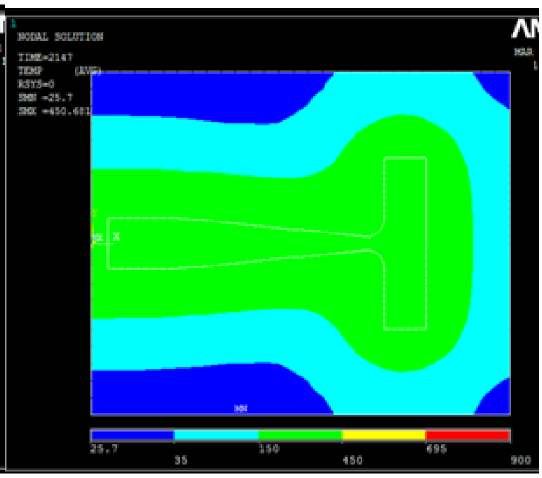

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IV. CONCLUSION

The objectives of this paper are fulfilled

1) Design the mold, gating/riser system for the circular Aluminum casting process and simulate the solidification of cube by Auto-cast software (demo)

2) Temperature distribution is shown in ANSYS i.e during solidification process

Casting Simulation is very powerful tool which is used to predict the growth of the process without physically performing the process. Solidification simulation provides iterative means of designing or modifying the feeding system. This reduces the overall cost of developing the method for new casting by minimizing the time as well as labor involved in it. Large number of trials can be performed quickly on simulation software package and optimum result can be obtained which ultimately increases the profit margin of foundry. Simulation also adds confidence to the methods engineer about the functionality of feeding system design.

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