FINITE ELEMENT ANALYSIS OF SOLIDIFICATION OF L-SHAPED CASTING USING ANSYS PARAMETRIC DESIGN LANGUAGE

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ABSTRACT

The complexity of process of solidification has urged the engineers to simulate the process before actually carrying out the casting procedure . Finite element method is used to simulate the heat transfer process accompanying the solidification process. The metal and the mould along with the air gap formation is accounted in the heat transfer simulation. Distortion of the casting is caused due to non-uniform shrinkage associated with the process. Residual stresses are induced in the final castings. In this thesis, transient heat transfer analysis of an L Shaped casting is presented. Contours of various parameters viz; thermal gradient, thermal flux and temperature distribution are obtained using ANSYS commercial finite element analysis code. The simulations are compared with available experimental data and the comparison is found to be good. Special considerations regarding the simulation of solidification process are also brought out.

Keyword: - *Casting, Solidification, Heat Transfer, Thermal Gradient, Flux*

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1. INTRODUCTION

Casting processes are essential in forming solid ingots or billets of metals for further processing, but moreover, a wide variety of casting processes are used in the production of finished or semi-finished components. Casting is preferred over other processes because it allows the production of complex shapes, without the need to introduce weaknesses when joining separate pieces, and is conservative of material compared with machining or cutting a shape from a large piece of metal. The methods available can achieve various standards of surface finish, microstructure, start-up cost, unit cost, and production volume, in order to suit many applications.

1.1 Solidification

Although the process of solidification process is complex in nature and the simulation of such process is required in industry before it is actually undertaken. Finite element method is used to simulate the heat transfer process accompanying the solidification process. The metal and the mould along with the air gap formation is accounted in the heat transfer simulation. Distortion of the casting is caused due to non-uniform shrinkage associated with the process. Residual stresses are induced in the final castings. Simulation of the shrinkage and the thermal stresses are also carried out using finite element methods. The material behaviour is considered as visco-plastic. The simulations are compared with available experimental data and the comparison is found to be good. Special considerations regarding the simulation of solidification process are also brought out.

The rate of solidification of a metal during casting is dictated by;

- The excess heat in the liquid metal on pouring,
- The amount of heat produced by the solidification of the metal (the latent heat of fusion),
- The rate at which this heat can be dissipated from the metal.

1.2 Significance of Biot Number in Solidification

A simple way to predict the way in which a casting will solidify, is using the Biot number, *Bi*, given by:

$$Bi = h\,L / k$$

where h is the heat transfer coefficient between the metal and the mould wall, K/L is the thermal conductance of the casting, calculated from K, the thermal conductivity of the liquid metal, and L, the length of the casting in the direction of the heat flow.

When the Biot number is large, heat is transferred quickly from the metal to the mould, but takes longer to reach the mould wall from the centre of the casting, resulting in a significant temperature gradient in the casting, and only a small temperature difference across the interface.

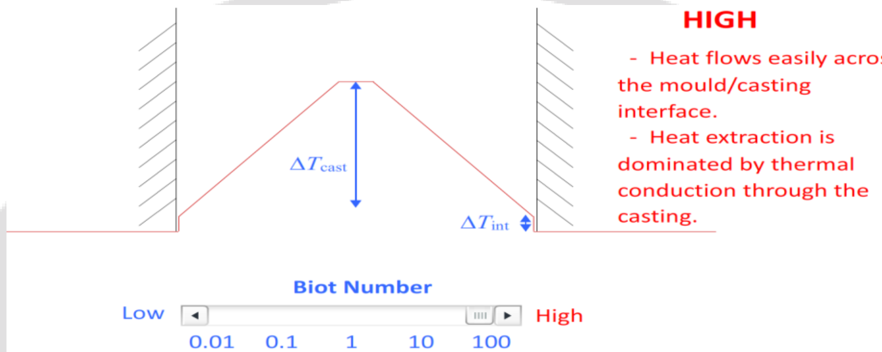

Figure 1:High Biot Number and Cooling Rate

When the Biot number is small, the transfer of heat to the edge of the casting is faster than the transfer of heat from the metal to the mould, resulting in a large temperature difference across the interface, leading to a significant temperature gradient in the casting.

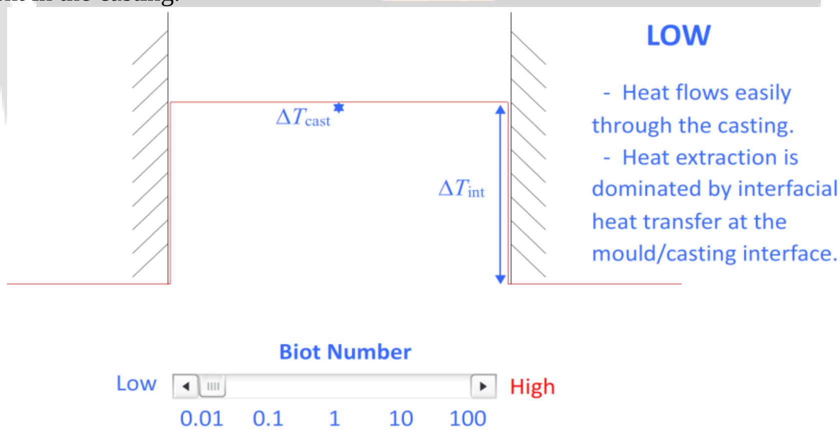

Figure 2: Low Biot Number and Cooling Rate

The primary and most obvious phenomenon controlling casting is the transfer of heat from the cooling metal to the mould. The early models of cooling of casting were straightforward heat conduction analysis. However, the mechanics of fluid flow are important for both mould-filling effects and physics based models of inter-dendritic porosity formation. Buoyancy effects, after the mould is full, exert varying degrees of influence during the cooling cycle depending on the thickness of the casting being produced. In addition, the analysis of the flow of various chemical species is very important for crystal growth and many thermo-fluid models today incorporate species flow.

2.0 PROBLEM FORMULATION

An L-shaped sand casting solidification has been selected as a subject of study for transient heat transfer analysis across the mould, the temperature distribution in the steel casting and the mould during a three-hour solidification process are presented. The casting is made in an L-shaped sand mould with four-inch thick walls. Conduction occurs between the steel and the sand mould, and convection occurs between the sand mould and the ambient air. The dimensions and the schematic of casting is presented below:

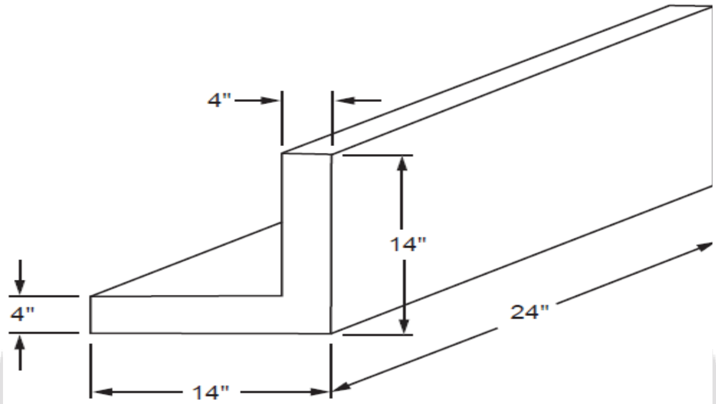

Figure 3.1 Schematic of L-Shaped Casting

2.1 Modelling of Casting in ANSYS

ANSYS Parametric Design Language (APDL Mechanical 14.5) has been used to develop the model for simulating the heat transfer phenomenon. In this study, a half cut symmetric 2 D model is considered for the sake of accuracy and less computational time requirements.

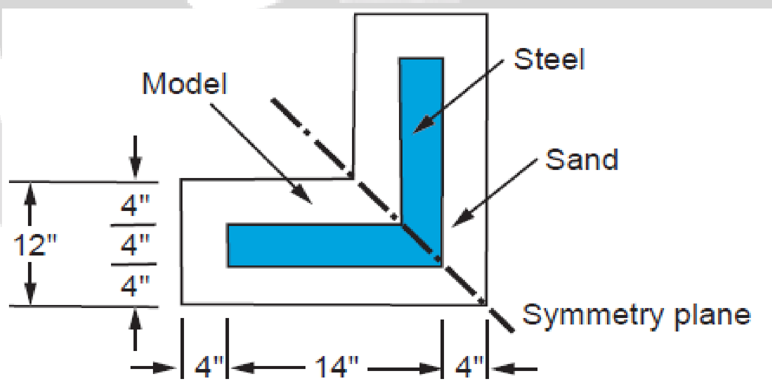

Figure 3.2 Half Cut Symmetric Model of casting

2.2 Meshing of the Domain

Due to symmetry of the domain, only lower half of the geometry is chosen for analysis in order to save computer memory and computational time. Meshing is an integral part of all computational phenomena . In present study, 4 noded quadrilateral elements are chosen to form the mesh of the domain. A node is a point of intersection of two lines in a grid and is common to many elements. The Finite Element Analysis works on the same principle that is calculates the value of an entity in the element using all the values of all the nodes surrounding that particular element. Figure 4.3 shows the meshed domain of the L shaped casting.

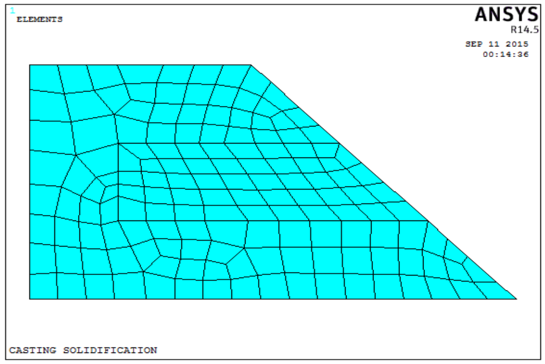

Figure 3.3 Mesh of the casting (Half Cut)

2.3 Material Properties of Sand and Steel

ANSYS solver needs various material properties of the sand and steel. Since, the present study deals with thermal analysis, therefore only thermal parameters like thermal conductivity, density, specific heat , enthalpy etc are required. Table 1 presents the material properties of sand and Table 2. the material properties of steel. Material properties for sand are constant. The steel casting has temperature dependent thermal conductivity and enthalpy. In order to converge the phase change non linearity , automatic time stepping has been incorporated to determine the proper time step increments.

Table 1 Material Properties of Sand

Item	**Units**
Conductivity (KXX)	0.025 BTU/ (hr in F)
Density (DENS)	0.054 lb/in^3
Specific Heat (C)	0.28 BTU/ lb-F

Table 2 Material Properties of Steel

Item	**Units**
Conductivity (KXX)	
At 0 F	1.44 BTU/ hr-in-F
At 2643 F	1.54
At 2750 F	1.22
At 2875 F	1.22
Enthalpy (ENTH)	
At 0 F	0.0 BTU/ in^3
At 2643 F	128.1
At 2750 F	163.8
At 2875 F	174.2
Initial Conditions	
Temperature of Steel	2875 F
Temperature of Sand	80 F
Convection Properties	
Film coefficient	0.014 BTU/ (hr-in^2-F)
Ambient Temperature	80 F

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2.4 Conductivity and Enthalpy Curves for Steel

Since the thermal conductivity and enthalpy of steel varies with temperature and the present study is a transient one, the variable conductivity and enthalpy is taken into consideration by ANSYS while solving the problem. Figure 3.4 and 3.5 show the conductivty and enthalpy curves for steel respectively.

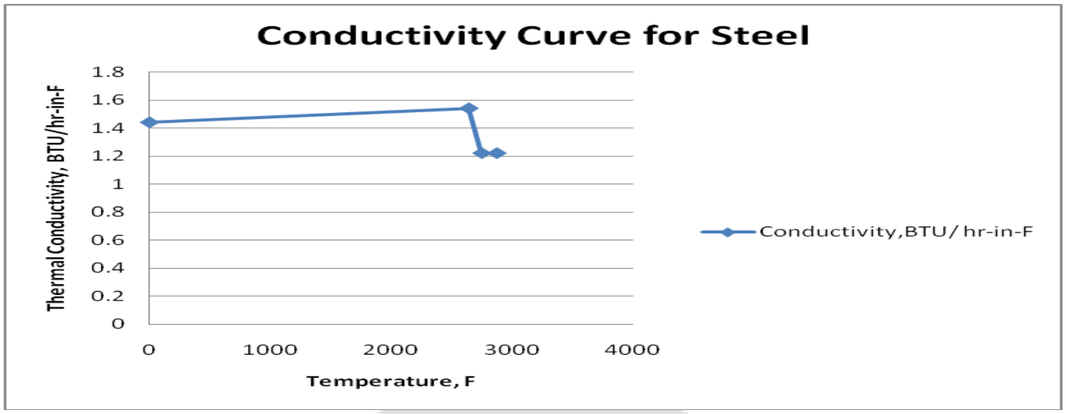

Figure 3.4: Conductivity Curve for Steel

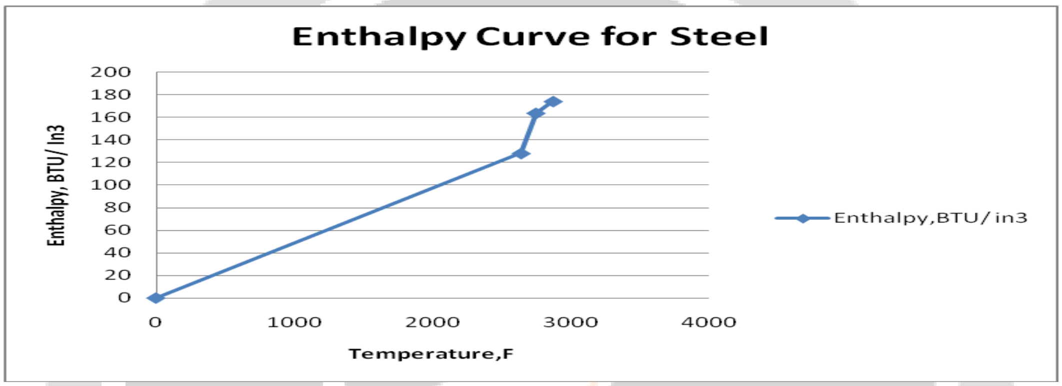

Figure 4.5: Enthalpy Curve for Steel

3.0 RESEARCH METHODOLOGY

3.1 Mathematical Modeling

The variation of temperature T with time in a two-dimensional region Ω bounded by a curve Γ, for both ingot and the mould is given by the equation,

$$\rho c \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k_x \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial T}{\partial y}\right) \quad \text{---------------------- (1)}$$

where ρc is the thermal capacity, k_x, k_y are the thermal conductivities in the x, y directions. The boundary conditions for this partial differential equation are the expressions for the heat fluxes between the ingot and mould These boundaries occur in two regions:

(a) Between ingot and inner wall of the mould,

$$q_{12} = h_{12}(T_1 - T_2) = \left({k_{12}}/{d_{12}}\right)(T_1 - T_2) \quad \text{-----------------------(2)}$$

where T_1 is the surface temperature of the ingot, T_2 is the temperature of the inner wall of the mould.

(b) Between outer wall of the mould and the surroundings,

$$q_{3\infty} = h_{3\infty}(T_3 - T_\infty) \quad \text{------------------------ (3)}$$

where *T*3 is the temperature of the outer wall of the mould, *T*¥ is the ambient temperature.

3.2 Finite Element Analysis Procedure using ANSYS

The general finite element modeling procedure consists of following steps:

i. Preferences
- Thermal

ii. Pre-processing
- Definition of Element Type
- Material Properties Definition.
- Model generation.
- Meshing

iii. Solution
- Defining initial condition
- Applying Boundary Condition
- Applying Load
- Solving for results

iv. Post processing
- Reading result file
- Viewing results

4. RESULTS AND DISCUSSIONS

4.1 Time/Frequency and Convergence Norm

As a nonlinear thermal analysis proceeds, ANSYS computes convergence norms with corresponding convergence criteria each equilibrium iteration. Available in both batch and interactive sessions, the Graphical Solution Tracking (GST) feature displays the computed convergence norms and criteria while the solution is in process. By default, GST is ON for interactive sessions and OFF for batch runs:

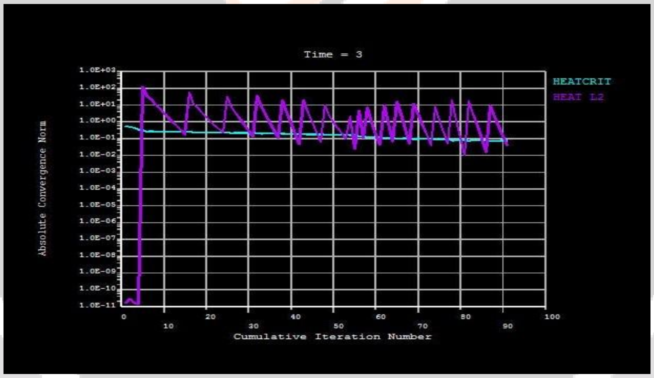

Figure 4.3 Absolute Convergence Norm

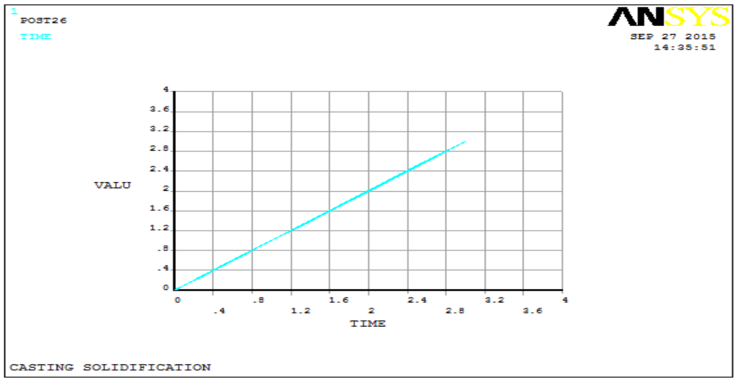

Figure 4.4: Time Frequency Convergence

4.2 Thermal Flux Vector Plot

Since the temperature of molten steel is 2875 F initially, the heat flows from steel to sand as shown in figure 4.3. The direction of arrows/vectors indicates the heat flux direction and in this case it is from steel casting to sand mould.

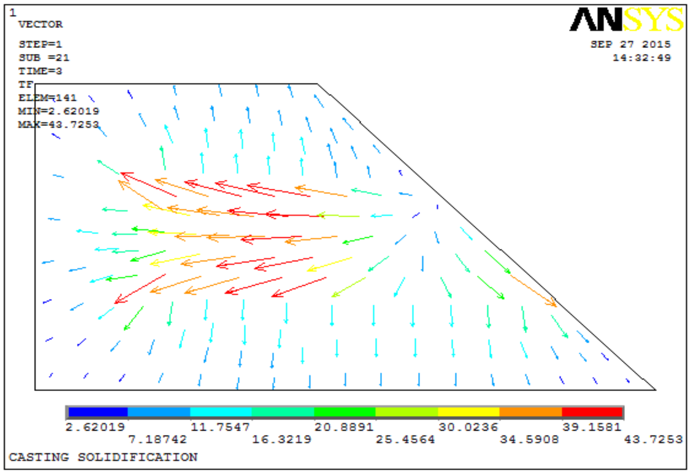

Figure 4.5 Vector Plot of Thermal Flux

4.3 Vector Plot of Thermal Gradient

The inward direction of thermal gradient vectors/arrows indicates that the gradient increases from mould to casting showing that the temperature increases in the direction of casting. Figure 4.4 shows the vector plot for thermal gradient.

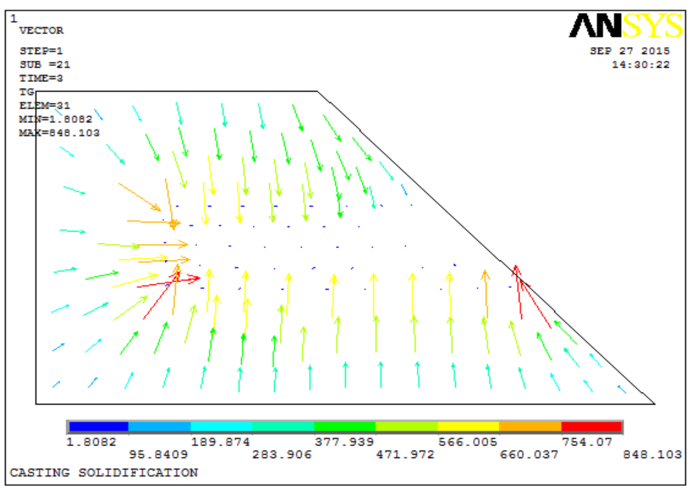

Figure 4.6 Vector Plot of Thermal Gradient

4.4 Two Dimensional Temperature Distribution in Casting

The initial temperatures of molten steel and sand mould are 2875 F and 80 F respectively. Inside the casting, there exists no thermal gradient in X-direction whereas a high thermal gradient can be observed in Y-direction in mould-casting area. The maximum temperature of 2675.18 F is observed in casting and air gap above and below the casting in the sand mould. The minimum temperature of 185.19 F is being observed in the sand mould corners much away from the casting. The big thermal gradient can be attributed to different thermal conductivities and initial temperatures of molten steel and sand mould. The following figure shows the temperature distribution in the sand mould and steel casting.

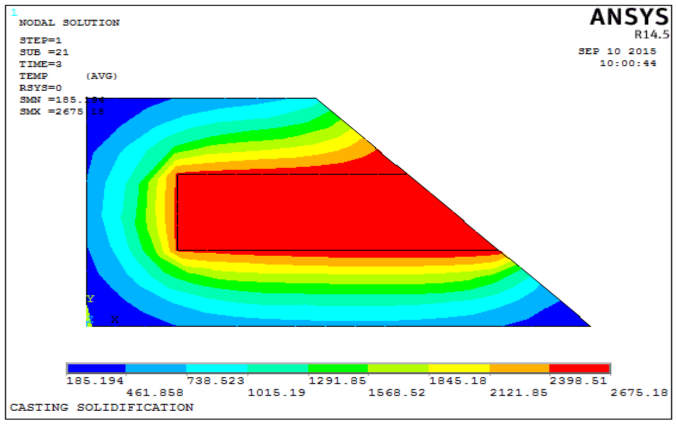

Figure 4.7: Temperature Distribution in the Mould- Casting 2D View

5.0 CONCLUSION

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, accurate casting design and proper design of gating system is necessary. This can be predicted and designed by means of computer simulation of casting solidification. By using thermal analysis approach the behaviour of the metal during melting and solidification could be determined. The results revealed that the transition temperatures were influenced by cooling or heating rates. Increasing heating as well as melting rates increased the melting initiation and completion to higher degree, respectively. Casting solidification simulation process is used to identify the defective locations in the castings from the generated time temperature contours. It is concluded that casting solidification simulation technology is used to eliminate defects like shrinkage, porosity and to locate the hot spot regions which helps to design the components effectively. The results obtained from transient thermal analysis of heat transfer between the steel casting and sand mould, formation of air gap at the casting-mould interface and heat transfer thereof , convective heat transfer between mould and ambient air are analysed and presented in this work.

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