FLUID FLOW CHARACTERISTICS AND THERMAL CONDUCTIVE HEAT FLUXES OF CONTINUOUS CASTING BY COMSOL MULTIPHYSICS

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ABSTRACT

Digital analysis of components, in particular is important when developing new products or optimizing designs. Through this project, using COMSOL Multi-physics software helps to understand a concept of continuous casting. In Continuous Casting of steel is an operation which is sensitive to a number of factors. It should be performed with great control and steadiness in such a way to produce safe casting operation and sound steel mechanical properties, and ensure a continuous process with limited delays.

In this study, effects of factors encountered in the process of continuous casting of steel billets on the thickness of solidified steel layer in the mould area and temperature distribution occurs in mould. Casting rates in terms of velocity magnitude and thermal heat conductive fluxes. Of these factors modelled are mould thickness, mould material, thermal conductivity and molten steel superheat. Simplified calculation were performed in which heat transfer equations governing the process solidification were solved using an explicit method of finite difference technique. The results showed that the most effective factor on solidified steel thickness in the mould is the magnitude of molten steel superheat prior to entering the mould.

Key words: COMSOL Multi-physics, Continuous Casting, Explicit method, Thermal heat conductive fluxes

1.INTRODUCTION:

CASTING: It is a manufacturing process by which liquid metal is poured in a mould cavity of a desired shape and remains to get solidified to room temperature. Sand casting., Parmentmould casting , Centrifugal casting , Investment casting and Continuous casting are the different types of casting process.

Continuous casting: Continuous casting, also called strand casting, is the process is shown in Fig.1, whereby molten metal is solidified into a "semi-finished" billet, bloom, or slab for subsequent rolling in the finishing mills. It allows lower-cost production of metal sections with better quality, due to the inherently lower costs of continuous, standardized production of a product, as well as providing increased control over the process through automation.

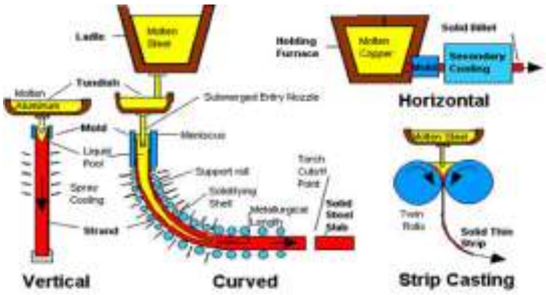


Fig:1 Continuous Casting Methods

Today a broad spectrum of options for simulation is available; researchers use everything from basic programming languages to various high-level packages implementing advanced methods. Though each of these techniques has its own unique attributes, they all share a common concern. COMSOL a flexible platform that allows even novice users to model all relevant physical aspects of their designs. Advanced users can go deeper and use their knowledge to develop customized solutions, applicable to their unique circumstances.

In which we simulates the process of continuous casting of a metal rod from a melted state to solidified state. To optimize the casting process in terms of casting rate and cooling, it is helpful to model the thermal and fluid dynamic aspects of the process. To get accurate results, we must model the melt flow field in combination with the heat transfer and phase change.The purpose of this model is to describe the transition from melt to solid in the flow in the continous casting process. The COMSOL Multiphysics model results show the temperature distribution, the position of the solidification regime and the glow field in the melt within the process at steady state. The model is a replica, with altered dimensions and material properties, of a real customer case. It was origially used to optimise the process.

2.LITERATURE REVIEW:

Hradecnad Moravicí (2013) carried out an investigation on as follows: Fluid flow and heat transfer calculations have been carried out in tundish and mould including different kind of submerged entry nozzles. The effect of different kind of tundish dams have been studied in a bloom tundish in steady state and transient conditions. CFD calculations were also carried out to study the effects of swirling flow inside the SEN as well as different kind of SEN nozzles on mould flow phenomena. The model, which is based on the Bayesian MLP neural network, includes 13 inputs from ladle cycle and the output is the tundish temperature. The results were good; the mean error for temperature was 3.4 °C.

Klaus Herfurth, Solingen (2009) simulates as follows: The results showed that the most effective factor on solidified steel thickness in the mould is the magnitude of molten steel superheat prior to entering the mould. Thermal conductivity of mould material showed little effect due to the small thickness of mould wall. Changing mould thickness showed some effect of solidification but was not significant.

3.THEORETICAL ANALYSIS OF CONTINUOUS CASTING

Continuous casting processes have two basic components to design, that is die and mold. Die is made up of very special alloyed steel to withstand at higher temperature conditions. Mold is to obtain a desired geometry (square , rectangle, rod…etc.) , after the mold then cooling takes place by providing water spray or open to atmospheric air conditions.

This design simulates the process of continuous casting of a metal rod from a melted state (as shown in fig.2) to optimize the casting process in terms of casting rate and cooling, it is helpful to model the thermal and fluid dynamic aspects of the process. The model includes the phase transition from melt to solid, both in terms of latent heat and the varying physical properties.

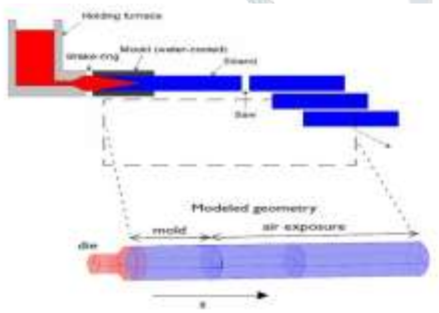


Fig:2 Continuous metal-casting process with an exploded view of the modelled section.

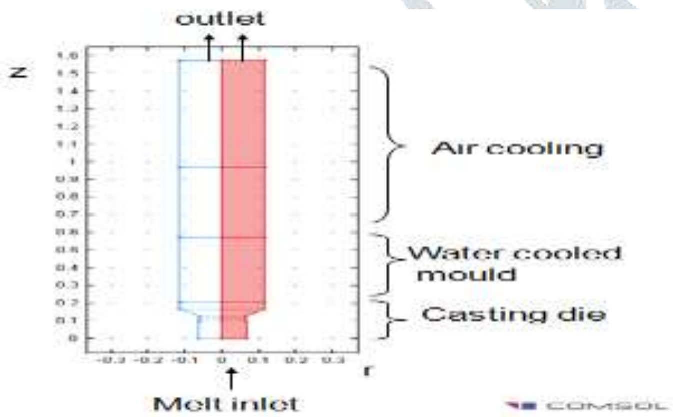


Fig: 3 Design of continuous casting model

Problem definition :

The casting process as being stationary using the Non-Isothermal Flow multi-physics interface, which combines heat transfer and fluid flow. The process operates at steady state, because it is a continuous process. The heat transport is described by the equation:

$$\nabla \cdot (-k\nabla T) = Q - (\rho C_p \mathbf{u} \cdot \nabla T)$$

where k, Cp, and Q denote thermal conductivity, specific heat, and heating power per unit volume (heat source term), respectively.

Modified Heat equation= $\rho(C_p + DL)\frac{dT}{dt} + \nabla \bullet (-k\nabla T) = Q$

The total amount of heat released per unit mass of alloy during the transition is given by the change in enthalpy, ΔH. In addition, the specific heat capacity, Cp, also changes considerably during the transition. The difference in specific heat before and after transition can be approximated by

$$\Delta C_p = \frac{\Delta H}{T}$$

Smoothing of thermal property functions using COMSOL's built in function: flc2hs

Apparent Heat capacity method is used through the Heat Transfer with Phase Change interface. The half-width of the transition interval, ΔT, is set to 10 K in this case, and represents half the transition temperature span. This models the laminar flow using the Non-Isothermal Flow interface, which describes the fluid velocity u, and the pressure p.

Reynolds number about 25 => Laminar flow.

Navier-Stokes :

$$\rho(\bar{u} \bullet \nabla)\bar{u} - \nabla \bullet \left[-p\bar{I} + \eta\left(\nabla\bar{u} + (\nabla\bar{u})^T\right)\right] = \bar{F}$$

Damping at the solid/liquid interface:

$$\bar{F} = \frac{(1-B)^2}{B^3 + k_1} k_2(\bar{u} - \bar{u}_{shell})$$

Fraction solid phase:

$$B = \begin{cases} 0 & T > T_m + dT \\ (T - T_m + dT)/2dT & T_m - dT \le T \le T_m + dT \\ 1 & T < T_m - dT \end{cases}$$

The model uses the parametric solver in combination with adaptive meshing to solve the problem efficiently. In particular, using an adaptive mesh makes it possible to resolve the steep gradients in the mushy zone at a comparatively low computational cost. Heat transfer in fluids takes place, here we are giving the inputs as heat flux, thermal conductivity values of mold materials and molten metal also. And specific heats thermal heat transfer coefficients (c_p) values.

Table:1 Material properties

Properties	Melt	Solid
ρ (kg/m3)	8500	8500
Cp (J/(kg·K)	530	380
k (W/(m·K)	200	200
η (Ns/m2)	0.0434	---

Where ρ, Cp, k and η denote density, specific heat capacity, thermal conductivity, and dynamic viscosity of the solid mold.

4.DESIGN GEOMETRY

Design of continuous casting process:

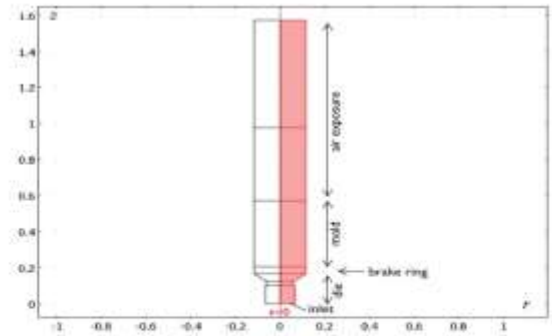
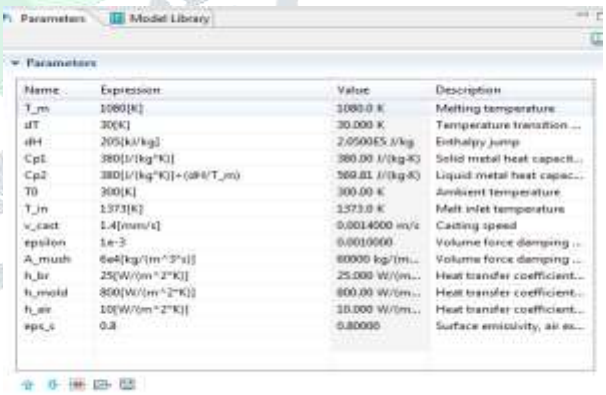


Fig: 4. 2D axi-symmetric model of the casting process.

Step by step process to design axi-symmetric model of die and mold by simulation software comsol multi-physics as shown in fig: 4. Define the parameters, equations and variables pertinent to the model (Global Definitions) as shown in fig.5.



Parameters | Model Library

Parameters

Name	Expression	Value	Description
T_m	1080[K]	1080.0 K	Melting temperature
dT	30[K]	30.000 K	Temperature transition ...
dH	205[kJ/kg]	2.0500E5 J/kg	Enthalpy jump
Cp1	380[J/(kg*K)]	380.00 J/(kg·K)	Solid metal heat capacit...
Cp2	380[J/(kg*K)]+(dH/T_m)	569.81 J/(kg·K)	Liquid metal heat capac...
T0	300[K]	300.00 K	Ambient temperature
T_in	1373[K]	1373.0 K	Melt inlet temperature
v_cast	1.4[mm/s]	0.0014000 m/s	Casting speed
epsilon	1e-3	0.0010000	Volume force damping ...
A_mush	6e4[kg/(m^3*s)]	60000 kg/(m...	Volume force damping ...
h_br	25[W/(m^2*K)]	25.000 W/(m...	Heat transfer coefficient...
h_mold	800[W/(m^2*K)]	800.00 W/(m...	Heat transfer coefficient...
h_air	10[W/(m^2*K)]	10.000 W/(m...	Heat transfer coefficient...
eps_s	0.8	0.80000	Surface emissivity, air ex...

Fig :5. Parameters and variables.

Die and mold design in comsol computer graphics as shown in fig:6, 7 and fig 8.

Fig : 6. die geometry

fig : 7. rectangle mold geometry

Fig: 8. union of die and mold with air exposure.

Material properties of mold and die as followed in shown in fig: 9. Materials used for die and mold are same in this case. We use cast steel materials for the both cases.

▸ Material Properties

▾ Material Contents

	Property	Name	Value	Unit	Property group
✓	Thermal conductivity	k	200	W/(...	Basic
✓	Density	rho	8500	kg/m³	Basic
✓	Heat capacity at constant pr...	Cp	Cp1	J/(kg...	Basic
✓	Ratio of specific heats	gam...	1	1	Basic
	Dynamic viscosity	mu	0.0434	Pa·s	Basic

Fig: 9 Material properties of mould and die.

Select the boundary, bulk and initial conditions for the system for each physics. Here we select inlet and out let conditions of fluid flow. These are the primary boundary conditions of the system. Then give amount of heat flux for die and mold materials to transmit heat to surroundings. Here the fluid flow is laminar flow we considered from inlet to exit of the mould as shown in given fig: 10.

Fig: 10 heat transfer in fluids and type of flow fluid.

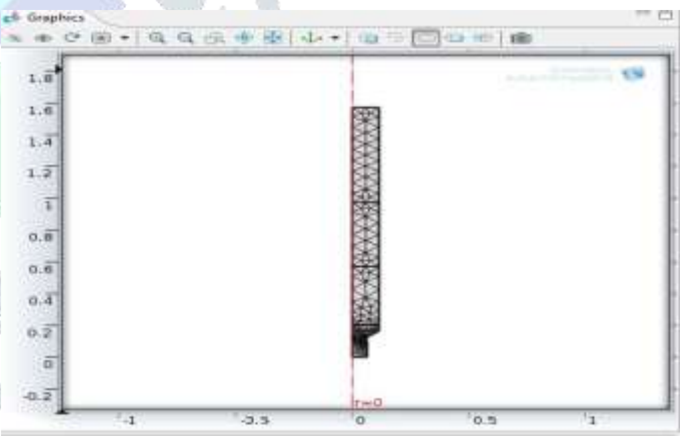


Fig: 11 Adaptive meshing is done

5.RESULTS AND DISCUSSION

The following figure:12. shows length of molten metal zone varies with various casting rates such as follows.

5.1.Length of Melted Zone:

Evaluating different casting rates (u)=>Process optimization

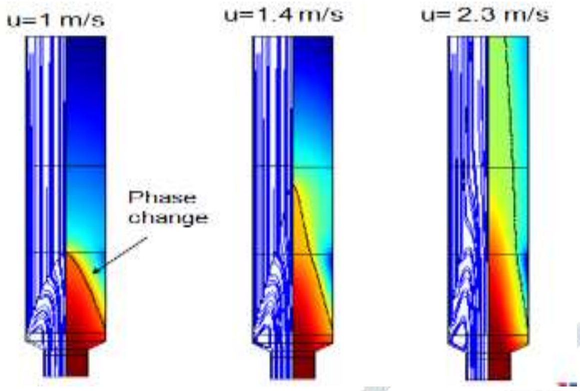


Fig:12. length of the melted zone at various velocities.

The phase transition occurs in a very narrow zone although the model uses a transition half width is shown in fig:13.

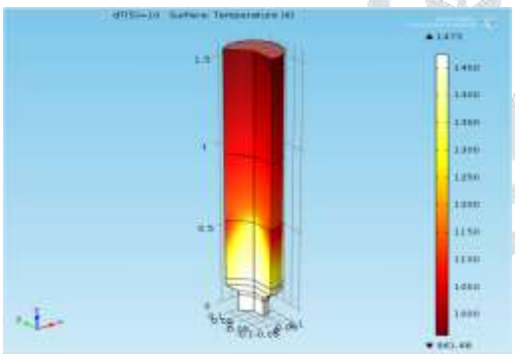


Fig: 13 3D temperature flow field

5.2.Temperature distribution and fraction of liquid phase

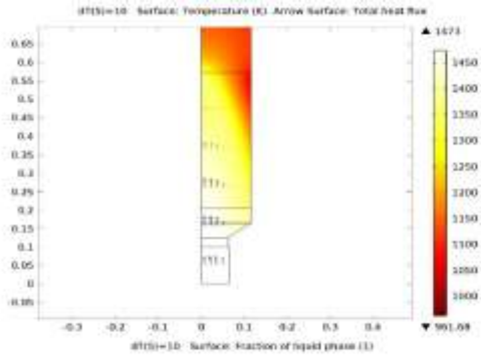


Fig :14. Temperature distribution

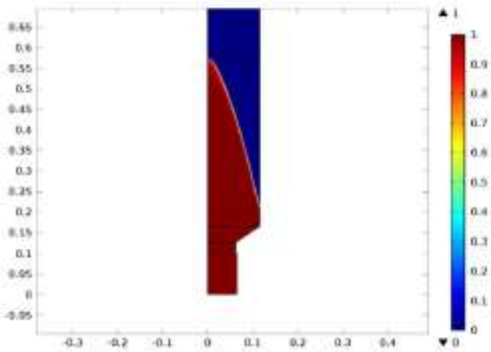


Fig:15. Fraction of liquid phase

The red color indicates that molten metal and then blue color denotes that the metal is solidified to atmospheric temperature conditions is shown in fig 14&15.

5.3.Velocity field with streamlines in the process:

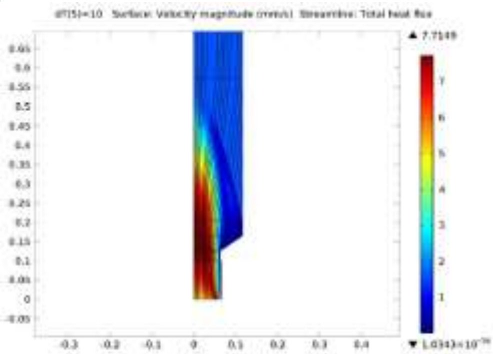


Fig: 16 Velocity field with streamlines in the lower part of the process's

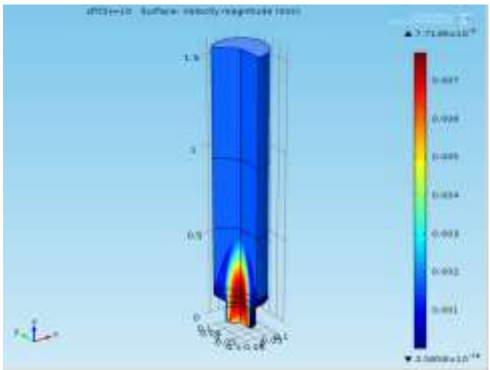


Fig: 17. 3D Velocity field.

In Fig.16, notice that the disturbance in the streamlines close to the die wall resulting in a vortex. This eddy flow could create problems with no uniform surface quality in a real process, pressure variation shows in figure:18 as follows

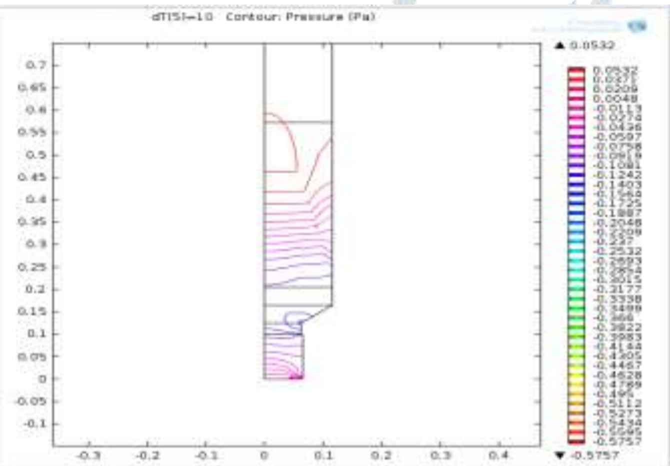


Fig :18 Pressure distribution

5.4.Conductive heat flux:

An interesting phenomenon of the process is the peak of conductive heat flux appearing in the center of the flow at the transition zone.

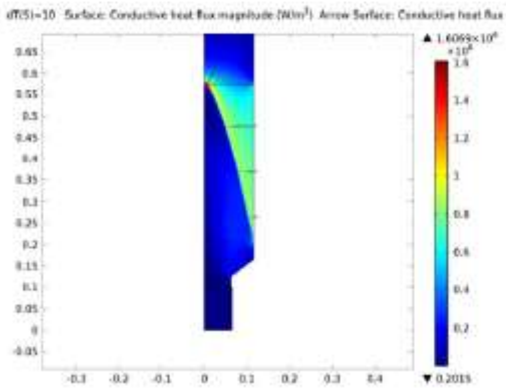


Fig :19 conductive heat flux (w/m^2)

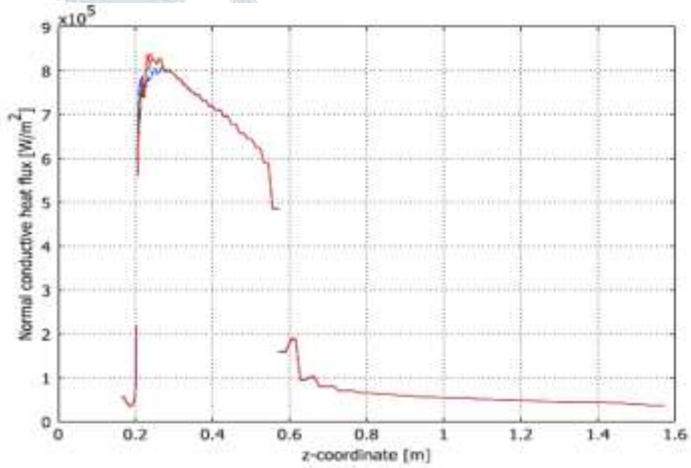


Fig :20 The cooling viewed as conductive heat flux in the domains (top) and along the outer boundary (the cooling zones) after the die (bottom).

Furthermore, by plotting the conductive heat flux at the outer boundary for the process as in the lower plot in Fig:20, can be see that a majority of the process cooling occurs in the mould. More interestingly, the heat flux varies along the mould wall length. This information can help in optimizing the cooling of the mould (that is, the cooling rate and choice of cooling method).

Table:2 simulation results at dT(5) = 10 K

Sl. no	Materials	Surface temperature (°C)	Conductive heat flux (w/m²)		Velocity magnitude (mm/s)
1	Cast steel	1473	1.6069 *10⁶	0.2015	7.7149
2	Copper	1325	0.985 *10⁶	0.1853	6.853
3	Aluminum	950	1.325 *10⁶	0.1966	7.635

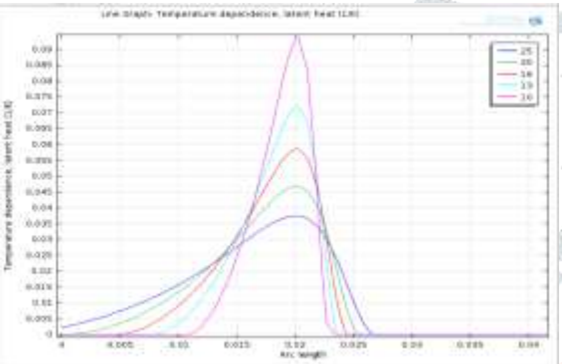


Fig: 21 graph shows dT parameter values.

From above fig: 21, the curves for the lower dT values, in particular dT = 10 K, are not entirely smooth. Thus, if you were to reduce dT further to model the casting of some pure metal, you would need to increase the mesh resolution.

6.CONCLUSION

In this the model describes the casting process in terms of temperature, flow field and phase transition occurs. The continuous casting is a the Heat Transfer module, it contains simulation tools to study the mechanisms of heat transfer – conduction, convection, and radiation – often in collaboration with other physics, such as structural mechanics, fluid dynamics, electromagnetic, and chemical reactions. Where as in fluid dynamics in casting process we consider laminar flow only from inlet to exit of mould. There is a significantly non-linear coupling between temperature and flow filed. By simulation of this casting thermal conductive heat fluxes and fluid flow characteristics are also easily evaluated in this process. Here in this mould material properties are changing such as thermal conductivity, density, and velocity or fluid flow parameters at various conditions and simulate the results as follows.

Temperature distribution and fraction of liquid phase values maximum is 1473 K at inlet of mould and minimum temperature is 961.68K at mushy zone. The phase transformation from liquid molten metal solidified state is clearly observed in it (as shown in fig no:5.4 in red and blue colors).

Velocity field with streamlines in this process as 7.714 (mm/s). Disturbance in streamlines create eddy flow problem at close to die. Then process engineer can avoid these problems.

The surface conductive heat flux magnitude is $1.609*10^6$ (W/m²) . By plotting the graph conductive heat flux Vs its length, majority of cooling occurs in mold, This helps us in optimizing the cooling of the mold.

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