SIMULATION OF SOLIDIFICATION PROCESS USED IN TWIN ROLL CASTING

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Abstract

Simulation of solidification processes has become an important tool for continuous casting applications. Modeling approaches must be determined adequately to clarify the process.
It is not easy to determine the boundary conditions needed to solve the problem. The commercial software's calco*soft-2D* and calco*soft-3D* have been used to model the process [1]. The software packages enables to quickly check the influence of each parameter separately and to gain an in-depth understanding of the process.

Keywords: Solidification, Twin-roll casting, 3D simulation, Phase change

Introduction

The twin roll casting process has gained more advantages due to its higher productivity and improved cast surface quality. Such process consists of two oppositely rotating water-cooled rolls, which are independently driven. These rolls are separated with a distance corresponding to the thickness of the strip being cast. Molten aluminum with uniform composition and temperature supplied from the holding furnace is degassed and filtered before being introduced into the head-box of the casting machine.

The Hunter *Speed Caster* ® has a 15° tilt, which allows regulation of the nozzle exit pressure by controlling of the head-box level. This feature stabilizes caster operation and permits smooth flow of the metal from the tip to the rolls. [2]

The head-box is connected to a planar pouring nozzle. This nozzle is usually referred as a tip and consists of two parallel thin-lipped slabs of ceramic material. Molten metal introduced into the casting machine via the nozzle solidifies between the rotating water-cooled rolls and leaves the casting machine in the form of a sheet. Molten metal enters the roll bite and is instantly chilled by the roll contact. [3]

Solidification of molten metal starts at the point of first metal-roll contact and is over before the kissing point. This requires a strict control on molten metal flow in the roll gap and heat transfer in the roll and strip. [4]

The simulation of solidification of metal processing techniques is very complex and valuable to understand the phenomenon. The processing technique can be simulated using 2D or 3D approach to understand the basics of the solidification event. The heat transfer and fluid flow are the key points for this simulation since the solidification occurs via forced convection and conduction.

Practical difficulties, preventing one to detect or measure the abnormalities in the flow patterns and temperature distribution in real casting operation, necessitate a numerical simulation method. In this paper, we examine the solidification patterns and temperature distribution of the molten aluminum and rolls throughout the model. The analysis is based on actual numerical values chosen from real casting operations in ASSAN Aluminium Plant.

Numerical Procedure

The modeling of continuous casting requires a specific treatment of the solid phase. In order to account for the transport of the solid, a dedicated transport term should be added to the equations. In the case of strip casting, one should take into account the fact that the solid shell, which is solidifying when in contact with the wheel, has not a straight trajectory, as in the case of conventional continuous casting. The solid shell has a curved trajectory, following the circular movement of the wheel. calco*soft* has the unique capability to define the transport velocity of the solid in a totally flexible way. Thus, it is possible to define a curved transport velocity of the solid, allowing a very accurate description of the strip casting process.

The goal of the present study is to analyze the velocity field, temperature gradient and solidification within the model geometry.

Fluid flow in presence of solidification and thermal analysis of the molten metal was performed by employing specifically designed 2-dimensional and 3-dimensional finite element softwares. Generally, the codes have been developed to simulate solidification processes [1], with a special emphasis on continuous casting.

2D Model geometry and mesh

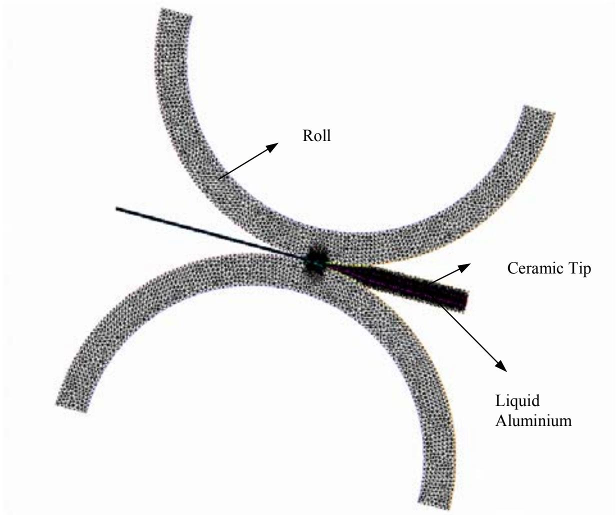

Figure 1: Model geometry and solution domain

The geometry consists of three main parts; the processed liquid/solid aluminium, the ceramic part (tip) and steel rollers.
The mesh where the basic unknowns are calculated inside the calculation domain has been shown in Figure 1. Quadrangular elements have been used to perform the mesh in the fluid domain while triangular elements are used in the roller and tip sections. 18833 elements and 14754 nodes are used.
Fine mesh structure has been constructed around roll bite where solidification details are quite important.

2D Assumptions

The numerical analysis requires acceptable assumptions to model the problem, which enables us to make better interpretation of the obtained results. The mathematical model involves the following assumptions. [4] [5]

- The steady state situation is modeled.
- Width/thickness ratio is very large and ignoring the end effects, the geometry of the process can be handled as two dimensional.
- The flow is assumed to be incompressible.
- The liquid aluminium is a newtonian fluid.
- Material properties except for thermal conductivity and specific heat are temperature independent.
- A constant value of contact heat transfer coefficient along the strip/roll interface was assumed.
- Heat losses by radiation were negligible.
- The solidification process was assumed to be growth controlled.
- Half section of rollers has been taken into account in the model.

The main parameters used in the presented calculation are as follows.

Liquid/solid aluminium :
Liquid density : 2368 kg/m^3
Latent heat : 9.4x10^8 J/m^3
Dynamic viscosity : 0.012 kg/ms
Linear thermal expansion coefficient : 25.5x10^{-6} 1/K
Liquidus/solidus temperature : 640-655 °C (3003 alloy)
Thickness : 6 mm
Sheet speed : 120 cm/min
Thermal conductivity (solid): 210-240 W/mK
Thermal conductivity (liquid): 90-96 W/mK
Specific heat : 890 – 1100 J/kgK

Tip section :
The material composition of the tip is a high-purity ceramic fiber and special bonding agents. The tip section is made of alumina-silica and thermal conductivity - specific heat values are as follows.
Specific heat : 700 J/kgK
Thermal conductivity : 0.066 - 0.15 W/mK

Shell :
The shell section of rollers are made of steel.
Thermal conductivity : 30 - 50 W/mK
Specific heat : 480 - 620 J/kgK
Revolution of speed : 2.5 rpm

2D Boundary Conditions

Velocity :
Uniform flow velocity has been assumed at the inlet section of the tip. Strip velocity was given at the outlet section of solid aluminium. No-slip boundary conditions were introduced at liquid aluminum-tip inner surfaces, which means that both velocity components are zero.

At inner and outer surface of rolls, normal velocity was specified as zero and tangential velocity was specified as a function of strip exit velocity.
At inner points of rollers revolution of speed is also defined.

Temperature and heat transfer coefficients :
Uniform temperature has been assumed at the inlet section of the tip. At the exit of the strip, zero heat flux was given.

An effective heat transfer coefficient due to convective heat transfer to the atmosphere from outer surface roll was taken as a constant.

The particular heat transfer coefficients between the tip/air and aluminum/tip boundaries were considered as constants.

At the strip/roll interface an air gap is formed as the liquid metal comes into contact with a graphite sprayed surface. Strip/roll heat transfer coefficient was taken as a constant (although it may be defined as temperature- or space-dependant).

There is no direct connection with the tip lips and steel rollers. At the tip exit the liquid aluminium is in contact with the air and then it touches the rollers. This is the drawback of modeling since free surface boundary condition can not be assigned. No-slip boundary condition is assigned at this surfaces.

It should be noted that upper and lower rollers rotates at opposite direction and that the strip is inclined by an angle of 15 degrees. As the gravity is nearly perpendicular to the strip, there is no symmetry (i.e. one should model both rolls).
Metal temperature and velocity values used at the inlet section of the tip are representing real casting values for 3003 alloy.

2D Results

The aim of this research is to find the effects of casting parameters and to demonstrate the capability of the modeling concept.

A proper casting machine should satisfy the following fundamental features.

- Proper set of casting parameters
- Quasi-uniform and symmetrical flow in both directions at the exit slot of the tip
- Uniform distribution of metal flow in plenum
- No fluctuations of fluid flow at the tip exit
- Uniform cooling conditions along shell channels inside the rollers

The calculation has been performed by using a Pentium 450 Mhz double processor with 512 MB Ram memory computer. Steady state solution is encountered where the basic unknowns are not changed at successive iterations.

The basic unknowns to be calculated at any point of the strip aluminium are velocity components (V_y , V_x) and temperature (T), whereas temperature is calculated in the tip and roller parts.

The analysis has been performed by using the above mentioned boundary conditions.

The quality of the cast strip depends on the sump depth. So it is important to discuss the effect of the various process variables on the sump depth. The sump depth is defined as the distance between the nozzle and the completion of solidification. Sheet speed, inlet velocity and strip/roll heat transfer coefficient have larger influence on the sump depth.

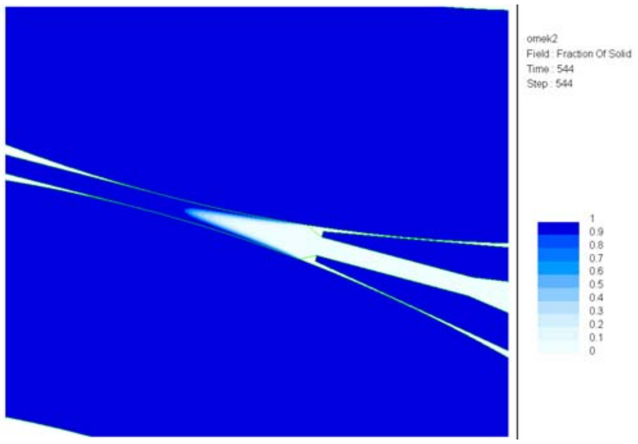

Figure 2: Calculated fraction of solid ratios for an inner roll heat transfer coefficient of 7500 W/mK

By taking the other calculation parameters constant, the effect of strip-roll interface and inner roll heat transfer coefficients has been analyzed. Figure 2 and 3 are showing the calculated fraction of solid ratios for two different inner roll heat transfer coefficients. The change in sump depth can be clearly seen. White regions indicates the liquid whereas dark color shows the solid regions.

One can well see the influence of the heat transfer coefficient on these results. The solidification is well completed before the kissing point of the rolls (i.e. the point where the two rolls are the closest) on Figure 2.

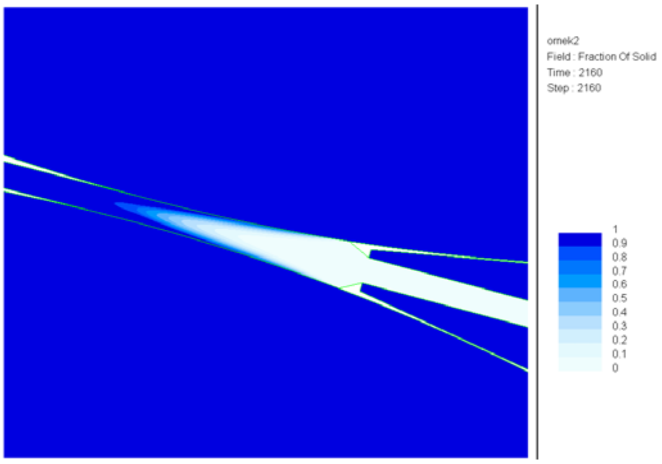

Figure 3: Calculated fraction of solid ratios for an inner roll heat transfer coefficient of 5000 W/mK

The gap heat transfer coefficient controls the removal of heat from the aluminum strip into the steel roll. The length of the sump depth increases as the inner roll heat transfer coefficient decreases, as indicated by the water temperature inside the rolls. The sump depth increases with superheat because the required time for the molten metal to solidify increases with the superheat in the metal.

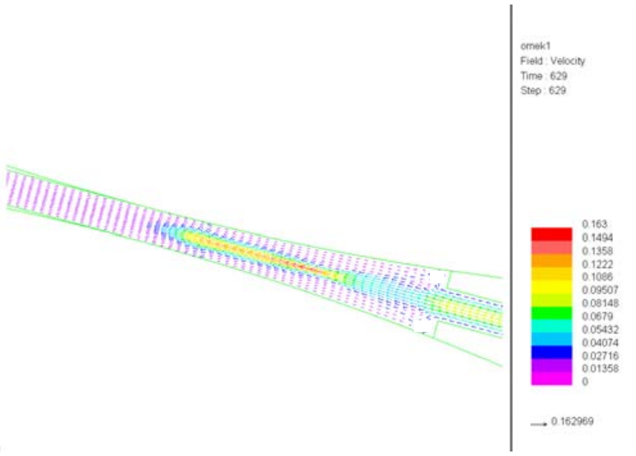

Figure 4: Calculated velocity contours inside liquid/solid aluminium

The velocity vectors calculated at the exit of the tip and between the rollers are shown in Figure 4. The velocity magnitude increases from 0 m/s to 0.16 m/s. One can see that once the aluminium solidifies the velocity of the solid phase is the same as the roll velocity.

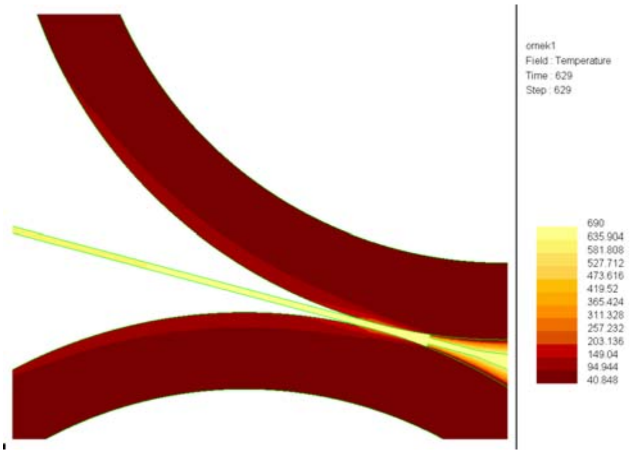

Figure 5: Calculated temperature profiles within the solution domain

The calculated temperature profile of the model is shown in Figure 5. The temperature contours on the outer part of the rollers vary from 150 °C to 300 °C.

3D simulation

If two dimensional simulation is a very efficient tool for fast predictions, it does not allow to model the side effects which are encountered in the real process. In this case, 3-D modeling is needed. In particular, if the inlet temperature or velocity distribution at the the tip are not even throughout the width of the machine, 3-D simulation can bring valuable information.

A 3-D model, corresponding to the real machine was designed. Due to symmetry, only half of the width is modeled. The geometry was meshed (by elevation of the 2D mesh), as shown in Figure 6. Then, the same conditions (material properties and boundary conditions) as the one described above for the 2D case were used in the 3-D calculation, except the inlet velocity profile. It was assumed that the inlet flow was set only on the central part of the tip (see Figure 9).

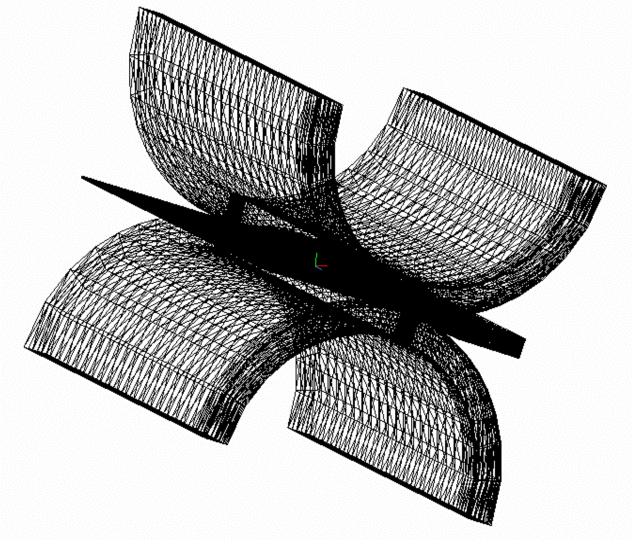

Figure 6: 3D model geometry and generated mesh

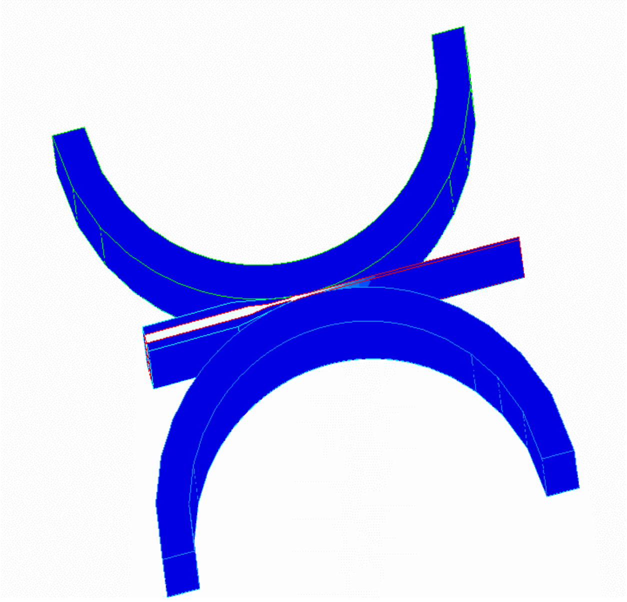

Figure 7: Calculated fraction of solid ratios at model geometry

Figure 7 is showing the fraction of solid, as calculated by the 3D FEM model, whereas the temperature distribution in the rollers are presented in Figure 8.

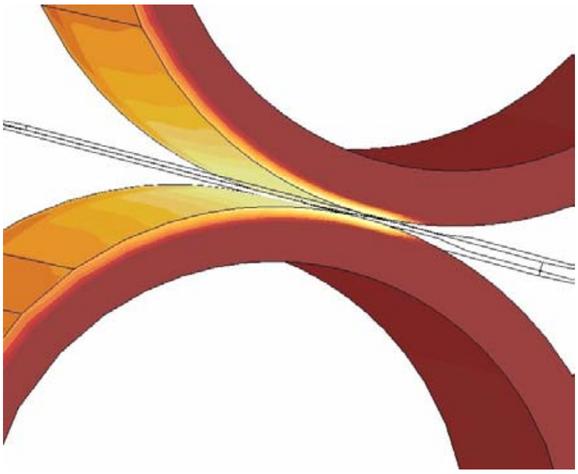

Figure 8 : Surface temperature of the rollers.

Figure 9 shows the temperature field on the top surface of the strip. One can very well see that due to the uneven inlet velocity distribution, the temperature field is not uniform. These very strong thermal inhomegeities along the width of the strip which are observed are very detrimental to the quality of the cast product.

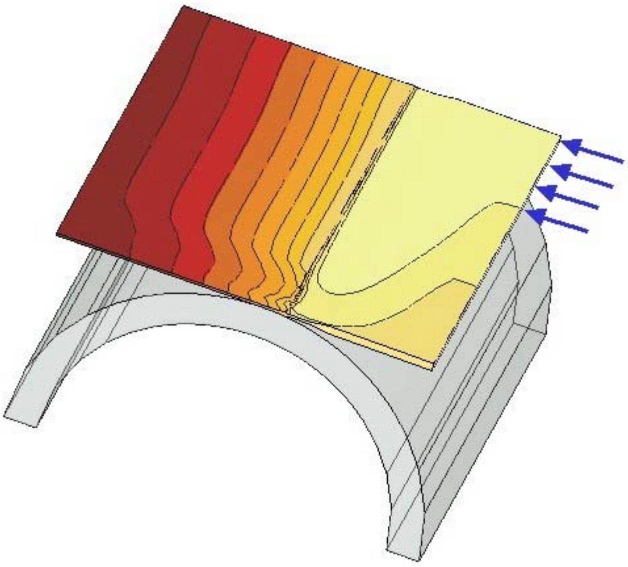

Figure 9 : Temperature field on the top surface of the strip. The inlet of the metal is shown by the arrows.

Conclusion

2-D and 3-D calculations were performed in order to better understand the strip casting process. First, 2-D calculations have allowed to test very quickly a large number of parameters. Then, 3-D calculations were performed to further tune the parameters obtained by the 2-D calculations. In this way, it was possible to obtain the best possible set of parameters in the shortest time. This paper is presenting the influence of a few parameters, in particular the influence of the strip-roller interface heat transfer coefficient and the non-uniform inlet velocity profile. It was shown that the position of the sump is very critical and is very strongly dependant upon the different casting parameters. These calculations have lead to a better understanding of the casting process and it was thus possible to optimize the machine.

These calculations have demonstrated that the strip casting process can be accurately modeled, when the appropriate material properties and boundary conditions are provided. Simulation is now a mature technology which is fast, reliable and efficient in order to test different configurations and process conditions in the design stage or to troubleshoot problems in the start-up or production stage.

Acknowledgements

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