

Effect of Casting Length on Solidification of Al-33 wt% Alloy in Twin-Roll Casting



Suvam Swayam Mohapatra and Seshadev Sahoo

Abstract Twin-roll casting is a combined process of casting and rolling to fabricate thin strips. It offers a little investment, and the casting parts are most probably refined microstructure, which attracts the interest of global casting industries. Therefore, it is necessary to study this process so that we can control the process. In the present study, steady-state modeling has been attempted for twin-roll strip casting with high casting speed by coupling the melt flow and solidification phenomena. With an increase in casting length, the cooling rate decreases, and solidified shell thickness increases as observed from the simulated results.

Keywords Twin-roll · Modeling · Solidification · Casting · Microstructure

1 Introduction

In today's world, the application of metal or alloy sheets has been grown up, and sheet metals can be found in airplane wings and fuselages, car bodies and medical tables, fan blades, etc. Since there is a vast application of metal or alloy sheet, every sheet manufacturing industry wants to make easier to produce sheet or strip from molten metal and wants to replace conventional operation procedures in their primary manufacturing processes. In the conventional sheet manufacturing process, quite an amount of time, energy, and capital are required to get a sheet from molten metal. So, in 1865, Sir Henry Bessemer made a breakthrough for sheet manufacturing industries; he invented the twin-roll casting process [1–3]. From this process, strips or sheets are directly produced from the melt by merging the casting and rolling process into a single step [4]. Mund et al. [5] did a simulation approach to observe that how solidification behavior gets affected by nozzle shape when twin-roll caster working at high speed. They observed that strips got prepared at nip position for circular shape nozzle, but for square, triangular, and elliptical shape, nozzle strip manufacturing

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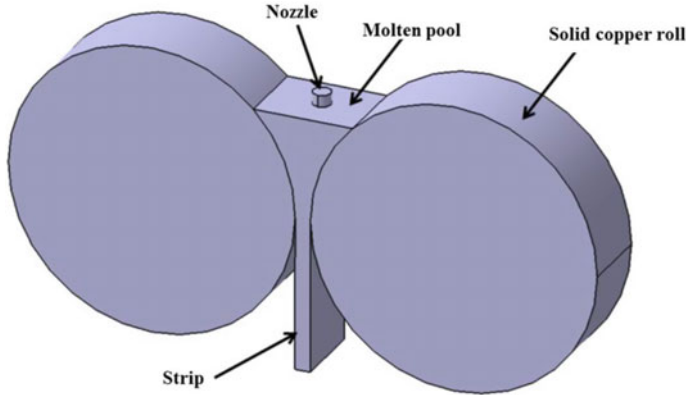


Fig. 1 Schematic representation of twin-roll casting

was not accomplished at nip point. A simulation was done by coupling the turbulent flow and heat transfer in the wedge-shaped pool of a twin-roll strip casting process with a vertical slit entry and bifurcated slit entry nozzle-types were used [6]. Since rolls also have great significance in this casting, research has been done on rolls [7]. A two-dimensional numerical model was considered for thermal analysis of the roll in the strip casting process in which heat transfer and deformation analysis of the casting roll was coupled and to study the thermal stress and displacement [8]. The microstructure of the strip must be controlled because further, if we want to modify the microstructure of the strip, on which the mechanical property of the strip depends, it may not be possible. The microstructure relies on the rate at which it cools and solidification front speed at a different position in the strand which also depends on processing conditions. In the present research work, a steady-state model has been developed to study the influence of casting length on melt flow and solidification characteristics of Al-33 wt% Cu alloy in the twin-roll casting process. Figure 1 is the representation of the twin-roll caster.

2 Mathematical Model

By considering the process practically, the numerical simulation was carried out with the consideration of the following assumptions:

1. Thermo-properties will not change concerning time.
2. Molten metal is Newtonian and incompressible.
3. There is no relative velocity of the strip to roll.
4. The process is symmetric along the centerline.
5. Heat transfer coefficient is considered constant at the liquid–metal interface.

6. Shrinkage of the solidified shell at kiss point is extremely low.
7. Rolls are considered non-deformable.

A two-dimensional heat transfer equation was solved during the numerical simulation. Details of the mathematical model were given by Sahoo et al. [9, 10].

The continuity equation is

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (1)$$

The momentum equation in the x -direction is

$$\frac{\partial p}{\partial x} + \frac{\partial(\rho uv)}{\partial x} = \frac{\partial}{\partial x} \left[\mu \frac{\partial u}{\partial x} \right] + S_x \quad (2)$$

The momentum equation in the y -direction is

$$\frac{\partial p}{\partial y} + \frac{\partial(\rho uv)}{\partial y} = \frac{\partial}{\partial y} \left[\mu \frac{\partial v}{\partial y} \right] + S_y \quad (3)$$

The energy equation is given by

$$\frac{\partial(\rho H)}{\partial t} + \nabla \cdot (\rho u H) = \nabla \cdot (K \nabla T) + S_h \quad (4)$$

where ρ is the density, H is the enthalpy, and S_h is the source term.

The model also considers the two-equation k - ε model of turbulence which was given by Sahoo et al. [9, 10].

Boundary conditions

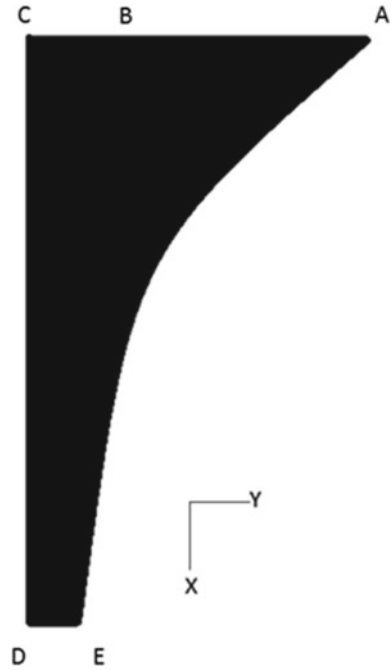
Figure 2 shows the computational domain used for numerical simulation.

- (i) At CB, the entry point of liquid metal, $V_x = V_{in}$, $V_y = 0$, $k = 0.05(V_x^2 + V_y^2)$, $\varepsilon = (C_\mu k^{1.5}/0.03) D_{in}$, $T_{in} = 851$ K.
- (ii) At AB surface, $\frac{\partial V_x}{\partial x} = \frac{\partial k}{\partial x} = \frac{\partial \varepsilon}{\partial x} = 0$, $V_x = 0$.
- (iii) At CD, $\frac{\partial V_x}{\partial y} = \frac{\partial k}{\partial y} = \frac{\partial \varepsilon}{\partial y} = 0$, $V_y = 0$.
- (iv) At AE surface, $V_x = V_{roll} \cos \theta$, $V_y = V_{roll} \sin \theta$, where V_{roll} is the speed at which roll is rotating, and θ is the angular position of the node on the roll surface.
- (v) At DE, $V_x = -V_{roll}$, $V_y = 0$.

3 Results and Discussions

In this research, numerical simulation of the casting of Al-33 wt% by varying casting length is carried out using ANSYS 19. A nozzle of 4 mm diameter is used to feed

Fig. 2 Computational domain taken for model development



liquid metal, and liquid metal temperature is taken as 851 K. The casting parameters which are used for simulation are given in Table 1.

From the temperature profiles (Fig. 3), it is observed that the temperature decreases for the casting length which varies 0 and 5 mm below the nip point, but when the casting length increases more than 5 mm below the roll nip point, there is a slight increase in temperature. When metal is in contact with the roll surface, the heat transfer rate is high because of the cooling system which is present within both the rolls. The cooling system helps the molten metal to decrease its temperature and get solidify in shell form which will get merged and form a strip. But when metal crosses the nip point, there is no more contact with the roll surface. The solidified metal encountered the ambient air which has an extremely low heat transfer

Table 1 Process parameters used for simulation

Parameters	Value
Roll diameter (m)	0.1524
Roll width (m)	0.0254
Speed at which casting is done (m/s)	0.7979
Liquid metal temperature (K)	851
Inlet diameter (m)	0.004
Casting length (mm)	0, 5, 10, 15

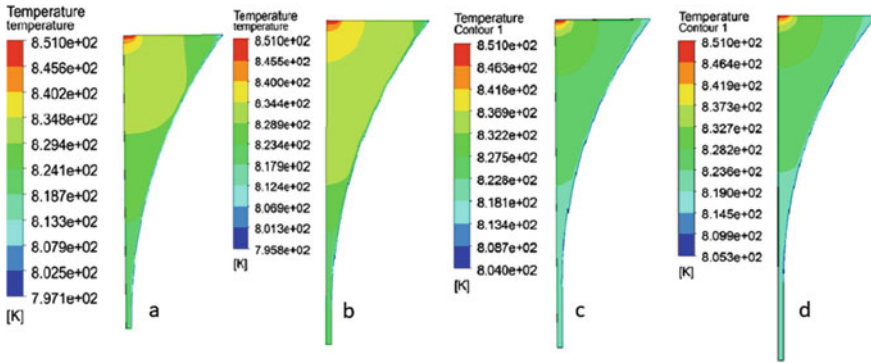


Fig. 3 Temperature profile of the molten pool with varying casting length, **a** 0 mm, **b** 5 mm, **c** 10 mm, and **d** 15 mm

coefficient. Therefore, the heat transfer rate gets decreased, and some amount of heat accumulation within the shells. This will result in a slight increase in temperature.

From the simulation result (Fig. 4), it is observed that solidification does not occur at the nip point or just after the nip point. When the casting increases up to 5 mm, the shells are not merged to become a strip. Similarly, when casting length increases up to 10 and 15 mm after the nip point, it is found that shells are about to merge to form a strip. At a nip point, the thickness of the shell is 0.459 mm, and with an increase in casting length up to 15 mm, the thickness of the shell is 0.655 mm as seen in Fig. 5. The thickness of the shell is increasing because of the dissipation of the heat.

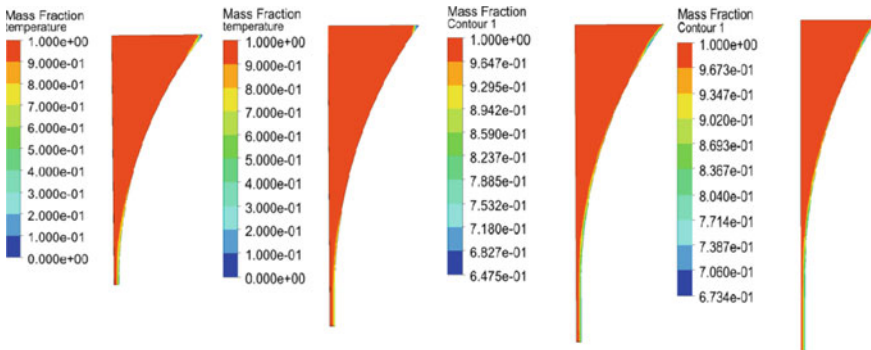
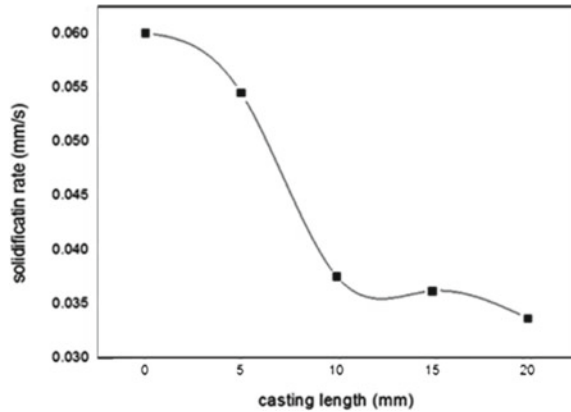


Fig. 4 Solidification contour with varying casting length, **a** 0 mm, **b** 5 mm, **c** 10 mm, and **d** 15 mm

Fig. 5 Change in solidification rate with casting length



4 Conclusions

Simulations were carried out using ANSYS 19 to investigate the solidification phenomena by changing casting length from 0 to 15 mm. From the analysis of the result, it is found that:

1. Solidified shells do not merge at the nip point or just after the nip point; instead of that, it merges much below the nip point; the shell thickness increases from 0.433 mm at the nip to 0.684 mm at 15 mm below the nip point.
2. With an increase in casting length, the temperature is slightly increased after the roll nip position due to the decrease in heat transfer rate.
3. The solidified shell thickness also decreases with an increase in casting length.

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