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Productivity, Strip Thickness, Roll Velocity and Pool Depth Relationships for Twin-roll Casting Process

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Abstract

Twin-roll casting has been widely used for producing thin strips and sheets. In twin-roll casting, molten metal is fed into the gap of a pair of counter-rotating, water-cooled rolls. In this paper, for given operating conditions and material properties, the closed-form relationship between productivity and strip thickness has been established. It gives an insight into the increase in productivity as strip thickness decreases. Also, the effects of roll velocity and pool depth on productivity are considered. To demonstrate its versatility and reliability, the results predicted by this model are compared with experimental data available in the literature and good agreements have been found.

Keywords: twin-roll casting, strip casting, productivity

1. Introduction

In the past decade, the technology of twin-roll casting has been widely investigated for the producing thin strips of both ferrous and non-ferrous alloys. The twin-roll caster provides a method for manufacturing continuous thin metal strips directly from molten metal, thus bypassing hot rolling operations and saving considerable energy and capital investment (Li, 1995a,b). It offers the advantage of combining the casting and rolling operations into one near-net-shape manufacturing process for the production of thin-gauge strips and sheets. In a typical twin-roll casting process, molten metal is fed through a pair of counter-rotating, water-cooled rolls as illustrated in Fig. 1. Solidification starts when the molten metal contacts the rolls. When the material exits the rolls, it is in the form of a sheet or thin strip. A rolling operation is considered to have occurred if the metal is completely solidified before exiting the rolls.

2. Relationship between productivity, strip thickness, roll velocity and pool delpth

In twin-roll casting, productivity is defined as the mass of the metal produced per unit time per unit width, i.e., ton/hr./m. For a fixed roll gap (l_f), the productivity can be increased by simply increasing the roll speed. However, there is a limitation to the roll speed; if the roll speed is too fast, it will cause a breakout problem in which the metal does not have enough time to solidify, thus exiting the rolls in a liquid state.

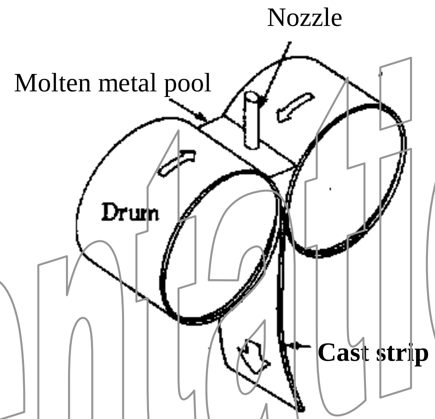

Figure 1. Schematic description of Twin-Roll Casting

In this section, it is shown that if the roll gap is decreased, while keeping the roll speed as high as possible, productivity can be greatly increased.

$$\text{Productivity, } Pd = \dot{m}/w = \rho \cdot U \cdot l_f \qquad (1)$$

where $\dot{m}$: mass flow rate
U : roll surface velocity (m/s)
l_f : roll gap
w : strip width

If we compare the productivity between two different roll speeds with the assumption that the solidified shells meet each other at the roll exit, i.e, $\theta = 0$, we get:

$$\frac{Pd_2}{Pd_1} = \frac{\dot{m}_2/w}{\dot{m}_1/w} = \frac{\rho U_2 l_{f2}}{\rho U_1 l_{f1}}$$

$$\frac{Pd_2}{Pd_1} = \frac{U_2}{U_1}\frac{l_{f2}}{l_{f1}} \qquad (2)$$

Given that the original roll gap and roll surface velocity are l_{f1} and U_1 respectively while l_{f2} and U_2 are the roll gap and roll surface velocity at the new settings. For productivity to increase, the right-hand side of Eq. (2) must be greater than unity.

Assuming that the solidification length is the same for both cases.

$$S = U_1 t_1 = U_2 t_2$$
$$\therefore \quad \frac{U_2}{U_1} = \frac{t_1}{t_2} \qquad (3)$$

The relationship between the solidifying thickness (s) and contact time(t) can be expressed as: $s \propto t^n$. Many researchers found from experiments that $s \propto t^{0.6\text{-}0.75}$. Let the exponent to be equal to n. The value of n is equal to 0.5 for the classical Stefan problem.

$$\frac{l_{f1}}{l_{f2}} = \left(\frac{t_1}{t_2}\right)^n \qquad (4)$$

Then Eq. (2) becomes,

$$\frac{\mathrm{Pd}_2}{\mathrm{Pd}_1} = \left(\frac{l_{f1}}{l_{f2}}\right)^{\frac{1}{n}-1} \qquad (5)$$

By defining Pd_2/Pd_1 as the productivity ratio and l_{f2}/l_{f1} as the strip thickness ratio, Figure 1 shows that if we reduce $l_{f2} \rightarrow 0$, Pd_2 can be greatly increased. If we keep all other process parameters constant, we can rearrange Eq. (5), which becomes:

$$\mathrm{Pd} \cdot l_f^{\frac{1}{n}-1} = \text{constant} \qquad (6)$$

Equation (6) gives a physical insight into the reason why there is an increase in productivity when strip thickness is decreased. This fact has been proved only in numerical models and experiments but never been explained in purely physical, non-numeric terms before. As we can see from Eq. (6), the only parameter that relates productivity and strip thickness is n and the physical value of n is always less than one. Because of this characteristic value of n, productivity is increased as we decrease the strip thickness. We now understand the basic relationship between productivity and strip thickness.

We can also derive the relationship between the roll velocity and the roll gap by using the same approach.

$$U \cdot l_f^{\frac{1}{n}} = \text{constant} \qquad (7)$$

The relationship in Eq. (7) is compared with the experimental result (Takuda, et al., 1990) in which stainless steel (SS 304) was used. As shown in Fig. 2, the relationship in Eq. (7) and the experimental results of Takuda, et al. (1990) are in good agreement. The value of n used in Fig. 8 is 0.75 and treated as a fitting parameter. As we decrease the strip thickness, we need to increase the casting speed. Equation (7) is also used to compare with the two-dimensional finite difference model of Takada, et al. (1990) As shown in Fig. 2, The results from the present analysis are in agreement with that of a more complicated model. It also shows that the constant in Eq. (7) depends on pool depth.

The potential application for our derivation can be seen by considering the two following cases. According to experiments by Yun, M. et al. (1991), they found an empirical relationship for the productivity, Pr, as a function of thickness:

$$\mathrm{Pd} = 4.18 l_f^{-0.62} \qquad (8)$$

Gupta and Sahai (1998) simulated twin-roll casting by the finite element method using FIDAP. They described the relationship between strip thickness and roll speed as follows.

$$l_f\,[\mathrm{mm}] = 0.8115\,(U[\mathrm{m/s}])^{-0.6319} \qquad (9)$$

Comparing Eq. (5) and Eq. (7), we can determine the exponent n to be equal to 0.617 or, solidification thickness $\propto$ (time)$^{0.617}$ Also, by comparing Eq. (7) and Eq. (9), we determine n = 0.6319 which is a negative of the exponent of Eq. (26) itself. Again, we can show that solidification thickness $\propto$ (time)$^{0.6319}$ for the case of Gupta and Sahai (1998). Thus, if we know the exponent n which is relatively easy to determine from a unidirectional solidification experiment and one data point from the twin-roll casting experiment, we can predict productivity as a function of the strip thickness easily.

Finally, the relationship of the roll velocity and the pool depth can be expressed as follows:

$$\frac{\omega}{\sin^{-1}\left(x_1/R\right)} = \text{constant} \qquad (10)$$

where x_1 : pool depth
R : roll radius
ω : angular velocity of the rolls

Figure 3 shows the plot of Eq. (10). The equation is plotted against the results obtained from Takuda, et al., (1990). As we see in Fig. 3, the results from the present study are in very good agreement with the Takuda model. It shows that the gradient is larger for smaller strip thicknesses. This means that control of the pool depth is of great technical importance when a thinner strip is cast (Takuda, et al., 1990).

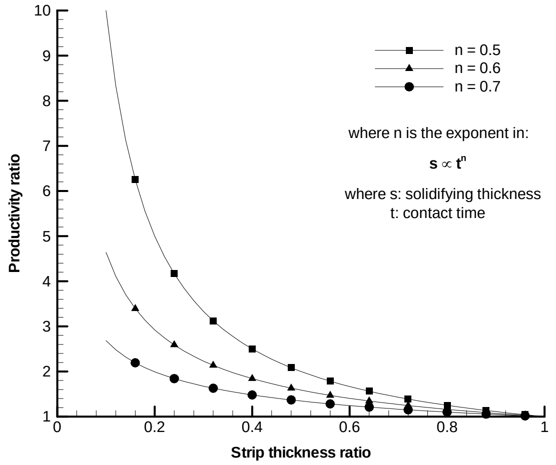

Figure 1. The effect of exponential, n, on the productivity ratio

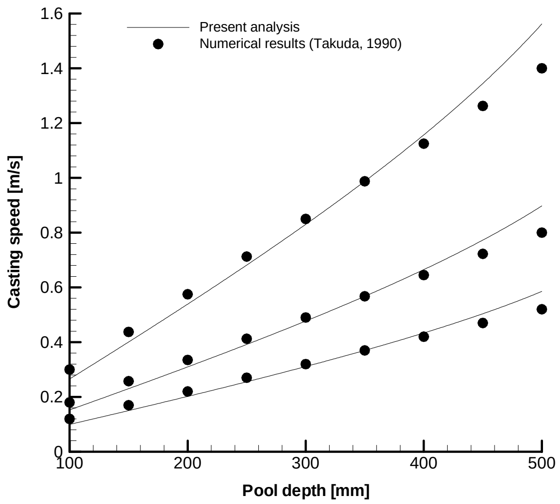

Figure 3. The relationship between casting speed and the pool depth at different roll gaps.

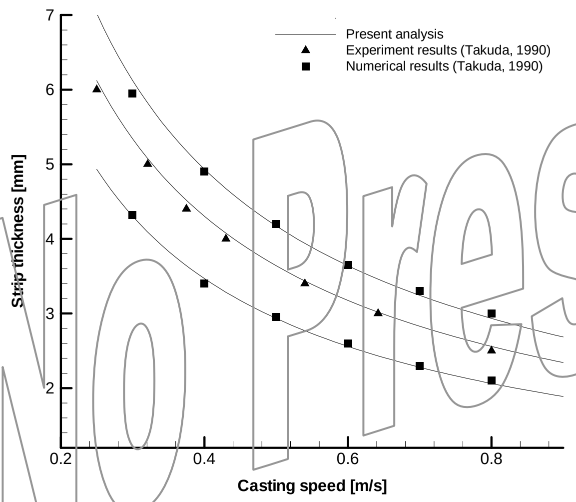

Figure 2. The relationship between casting speed and the strip thickness

3. Conclusion

The productivity can be expressed as a function of the strip thickness or roll gap as stated in Eq. (6). It can be seen that the productivity is increased when the strip thickness decreases because the exponent, n, is less than one. The relationships between the strip thickness, productivity, roll velocity, and pool depth are developed in this paper. Results from the present model are in good agreement with data available in the literature. They are excellent for a parametric study among process variables.

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