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RESEARCH ON CALCULATION MODEL OF ROLLING FORCE IN TWIN ROLL INCLINED STRIP CASTING PROCESS

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For the twin roll inclined strip casting process, the tilt angle function is introduced to describe the casting process, and the mathematical model of the calculation of the rolling force coupled with the tilt angle function is proposed, and the relationship between the influence of the tilt angle on the rolling force is derived, thus enriching the casting and rolling theory.

Keywords: casting, twin roll strip, rolling force, mathematical model

INTRODUCTION

Compared with the traditional continuous casting process, the twin roll casting process eliminates the bloom rolling, heating, and hot rolling processes, which shortens the production process, increases the production speed, reduces the equipment investment, reduces energy consumption, reduces environmental pollution, improves the sheet performance, and the thickness of the produced sheet is thinner [1-2]. In the vertical twin roll casting, due to the horizontal placement of the twin roll, the sheet metal exit direction is perpendicular to the ground, and the length of the sheet is limited by the height of the cast-rolling machine from the ground, which makes it more difficult to curl, especially for the magnesium alloy sheet with the advantages of excellent performance and abundant resources. In order to solve this problem, tilting the cast-rolling machine at a certain angle to change the direction of the output plate is a suitable solution. Compared with horizontal twin roll casting, twin roll inclined strip casting can reduce gravity segregation and increase the casting speed; and compared with vertical twin roll casting, it can reduce bending stress and curling difficulty; compared with unequal diameter twin roll casting, the control difficulty can be reduced. Many experts and scholars at home and abroad have carried out a lot of research work on twin roll casting, but there has not been a systematic study on equal-diameter twin roll inclined casting. This paper focuses on the research of the rolling force in twin roll inclined strip casting process, and proposes a mathematical model for calculating the rolling force of coupled inclination function.

SYSTEM MODEL

During the twin-roll tilting casting process, due to the tilt of the casting roll stand, one side of the shifting roll is raised by the hydraulic system, which causes the gravity of the shifting roll to produce the component $F1 = mg \sin \beta$ which is along the direction parallel to the line connecting the centers of the two casting rolls and the component $F2 = mg \sin \beta$ which is perpendicular to the line connecting the two roll centers. The rolling force is equal to the combined force of the gravity component $F1$ and the hydraulic pressure and friction generated by the hydraulic cylinder. The twin roll inclined strip casting increases the influence of the gravity component $F1$ and changes the influence of the frictional force compared with the vertical casting-rolling[3], and the degree of influence is directly related to the angle of inclination.

Cast-rolling area analysis

Compared with vertical twin roll, the shape and area of the cast-rolling area of the twin roll tilting casting have changed. The shape is asymmetrical and the area is reduced, which will inevitably directly affect the rolling

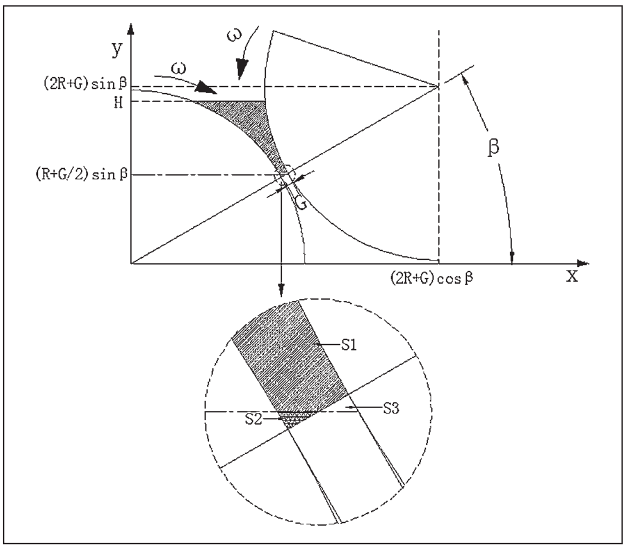

Figure 1 Calculation of side area of molten pool analysis

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force. When calculating the rolling force using the differential element method, the upper and lower limits of the integral need to be determined. Because the liquid level of the molten pool is parallel to the x-axis, the upper limit of the integral can be directly determined as y=H. However, due to the tilt, the exit direction of the board is related to the tilt angle and is not perpendicular to the x-axis. Therefore, the lower limit of the integral is a diagonal line, which increases the computational complexity. It can be seen from Figure 1 that S1+S2=S1+S3 can be deduced from S2=S3. For a simpler calculation, the lower limit of integration is replaced by a horizontal straight line passing through the midpoint of the line connecting the centers of two circles, i.e. $y=(R+\frac{G}{2})\sin\beta$, G denotes the roll gap and R denotes the roll radius.

Calculation model of rolling force

With the rapid decrease of the temperature, the liquid metal forms a solidified shell on the surface of the casting roller. The intersection of the solidified shells of the two rolls is called the solidification bonding point K_p. Starting from the solidification bonding point, the solidified shells of the two rolls come into contact with each other and occur viscoplastic deformation, and the twin rolls exert rolling force F on the metal materials. The unstable rolling force will lead to the low surface quality of the sheet, cause thermal cracking and plate breakage, and even affect the internal structure of the sheet [4-5]. Only a stable control of the rolling force can make the casting process go smoothly, so a rolling force calculation model must be established.

Above the solidification junction, the metal material is in the liquid zone. Due to the shear stress of viscous fluid is much smaller than the viscoplastic stress of solid for metal materials, the rolling force generated in this interval can be regarded as constant F_0. Considering the complexity of two-roll tilting casting, it is more difficult to determine the position of solidification bonding point, so the solidification point coefficient δ_s, and then the solidification bonding point's height $H_k = H\delta_s$ are introduced, where H is the height of molten pool. Assuming that the width of the cast-rolled slab along the roll body direction is the same, and the strain along the roll body direction is constant under the constraint of the side sealing plate, the calculation of the cast-rolling force can be simplified as a plane problem. The force analysis of the differential element in the cast-rolling deformation zone is shown in Figure 2.

For any differential body in the solid phase region shown in the shadow section in Figure 2, there are unit pressure force P_n and unit frictional force τ_n from the casting roll. Considering that the differential arc length of the contact between the solidification metal and the casting roller can be approximately expressed as $ds \approx dy/\cos\theta$, where θ is the angle between the horizontal axis and the connection line between the roller center and the differ-

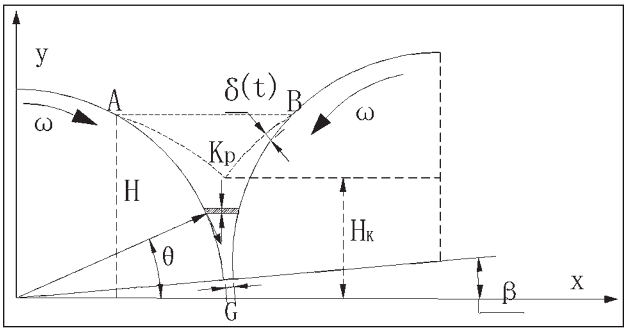

Figure 2 Force analysis on the differential unit in the deformation zone of the twin roll inclined casting

ential element body, and the rolling force is combined by all of the horizontal component on the contact surface, the rolling force can be expressed as follows:

$$F = L\left(\int_{(R+\frac{G}{2})\sin\beta}^{H_k} P_n dy + \int_{(R+\frac{G}{2})\sin\beta}^{H_k} \tau_n \tan\theta dy\right) + F_0 \quad (1)$$

In the formula, L is the width of casting roll surface, and H_k is the height of solidification bonding point. Considering that the value of $\tau_n \tan\theta$ is negligible for p, the formula (1) can be simplified as:

$$F = L\int_{(R+\frac{G}{2})\sin\beta}^{H_k} P_n dy + F_0 \quad (2)$$

The vertical component of the resultant force on the contact surface between the differential body and the casting roll can be expressed as $2(P_n\tan\theta dy - \tau_n dy)$, and the stress resultant force in the vertical direction of the differential body can be expressed as $(\sigma_k + d\sigma_y)(x + dx) - x\sigma_y$. Since the total resultant force in the vertical direction of the differential body is zero, the following equation can be obtained:

$$x\sigma_y - (\sigma_y + d\sigma_y)(x+dx) - \\ -(P_n \frac{dy}{\cos\theta}\sin\theta - \tau_n \frac{dy}{\cos\theta}\csc\theta) = 0 \quad (3)$$

Expand the formula (3), ignoring the second order infinitesimal items, and taking into account $\tan\theta = dx/dy$, then the following formula is deduced:

$$\frac{d\sigma_y}{dy} + \frac{\sigma_y - 2P_n}{x}\frac{dx}{dy} + 2\frac{\tau_n}{x} = 0 \quad (4)$$

Similarly, the total resultant force in the horizontal direction of the differential body $P_n dy - \tau_n \tan\theta dy - \sigma_x dy$ should also be zero. If the smaller item $\tau_n \tan\theta dy$ is ignored, the following equation can be obtained:

$$\sigma_x = P_n \quad (5)$$

Based on the Mises Yield Criterion, the horizontal and vertical stresses on the differential body are related as follows:

$$\sigma_x - \sigma_y = \beta_\sigma \sigma_s \\ \beta_\sigma = \frac{2}{\sqrt{3+\mu_\sigma^2}} \\ \mu_\sigma = \frac{\sigma_z - (\sigma_x+\sigma_y)/2}{(\sigma_x - \sigma_y)/2} \quad (6)$$

In the formula, β_σ is the influence coefficient of intermediate principal stress, μ_σ is the Rhode stress parameter, σ_s is the yield stress of a metal compressed or extended in a certain direction, which is constant for the same metal. Taking differentials on both sides of formula (6), the equation $d\sigma_x = d\sigma_y$ can be obtained.

Considering the characteristics of casting-rolling process, the deformation area of metal materials is mainly concentrated at the twin roll gap, so $d_x \approx 0$, $x \approx G$ can be obtained. Assuming that the deformation of cast-rolling material satisfies the maximum friction criterion, i.e. $\tau_n = \frac{K}{2}$, the formula (4) can be simplified as:

$$\frac{dP_n}{dy} = -\frac{K}{G} \tag{7}$$

In the formula, K is the yield coefficient of cast-rolled metal materials, which can be regarded as a constant at the specified temperature.

By linearizing formula (7) in the interval [y, HK], the following formula can be obtained:

$$P_n = \frac{K}{G}(H_k - y) \tag{8}$$

By substituting formula (8) into formula (2), the calculation model of rolling force can be obtained as follows:

$$F = \frac{LK}{2G}\left(H_k - (R + \frac{G}{2}\sin\beta\right)^2 + F_0 \tag{9}$$

It can be seen from Formula (9) that if the rolling force is to be stable in the casting-rolling process, then the roll gap, the position of the solidification junction and the inclination angle need to be kept stable accordingly. A compensation term is introduced into the new calculation model of rolling force for equal diameter twin roll inclined strip casting, the effect of inclination angle on rolling force was also considered.

CONCLUSIONS

On the basis of the deliberate analysis of the law of equal diameter twin roll inclined strip casting process, the calculation model of rolling force in twin roll inclined strip casting process is established. According to the mathematical model, the influence of tilting angle on the rolling force is obtained, which enriches the casting theory and lays the foundation for the follow-up study of twin roll tilting roll casting.

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Note: The responsible translators for English language is J. Wang-University of Science and Technology Liaoning, China