Preset-up Models of Roll Gap Curves for Twin-Roll Strip Casting Processing

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Abstract: Based on the analysis of bending deformation and thermal expansion of the roll, the preset-up models of the roll gap curves in twin-roll strip casting are investigated by using finite element analysis and experimental data.
Taking typical cast-rolling roll as an example, the roll gap curves under different casting rolling pressure and temperature are simulated according to the measured value of thermocouple in the casting rolling zone and the infrared thermometer near the casting roll product. The change rules of cast-rolling roll gap curve at the middle and edge marked points under different cast-rolling pressure and temperature are expressed by cubic polynomial and linear equations respectively. The preset-up models of roll gap curves can be obtained from these equations, which can help to control the thickness and flatness of cast-rolling strip.

Keywords: Twin roll strip casting; Roll gap curve; Preset-up Model; Cast-rolling pressure; Cast-rolling temperature

1 Introduction

Twin roll strip casting has been widely used to fabricate stainless steel, aluminum and magnesium alloys, and clad strip in recent years. It can save up to 70% equipment investment and 30-40% production cost compared with conventional process including continuously casting, hot rolling and cold rolling[1-4]. However, twin roll strip casting is a very complicated process. In the process, the molten metal is fed through a nozzle into the gap of the two rotating rolls, and then the flowing melt is cooled while the heat transferred from the melt to the roll is removed by a suitable roll cooling system[5] in which the heat transfer, solidification and plastic deformation[6,7] can be completed in less than 1s. The temperature of pouring zone between the melt metal and the roll is rapidly cooled from 973 K(900℃)[8] to 50℃[9]. With rapidly coupled change of temperature and rolling force, Frequent bending deformation and

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thermal expansion and contraction of roll sleeve have an enormous effect on the shape of roll gap. There are still several practical difficulties to get the satisfied thickness and flatness quality of products. Since 1994, many attentions are paid to the thermal flow and the material solidification behaviors in the twin strip casting process[10,11], and the effort of temperature or strain rate on the flow stress behavior[12], only a few results are related to the roll[13,14] and the roll sleeve[15-17].

Many preliminary study on roll force, casting temperature and casting speed and process parameters have been carried out, the modeling method is widely used to describe the quantitative relationships of the important control parameters, such as the roll speed, height of pool region, outlet size of nozzle, solidification profile and the final point of solidification and discover the effect of the casting speed, pouring temperature of melt, and roll gap on the flow and temperature field in a twin roll strip casting. A sticking mode against the roll shell based on Coulomb friction law is proposed to calculate the rolling force and forward slip[18]. Neural networks based on feed forward training algorithm in Bayesian regularization are introduced to establish he position model of kiss points [16]. Some thermal models[11,17-22] of the thin strip casting process have been established to evaluate or predict the casting temperature. However, few attentions are focused on the effect of roll deformation behavior on the quality of twin roll strip.

In the cast-rolling process, the profile curve of cast-rolling roll, namely the outside surface geometrical shape of cast-rolling roll, is effected greatly on casting pressure and cast-rolling thermal expansion. The larger cast-rolling pressure, the larger bending deformation of rolls, and the higher casting temperature, the larger thermal expansion. The overlap between the casting rolling pressure and the temperature field leads to deviations in product thickness and flatness. Therefore, the study of the thickness and convexity setting model based on roll bending deformation and thermal expansion is of great significance to the thickness and flatness control during roll casting.

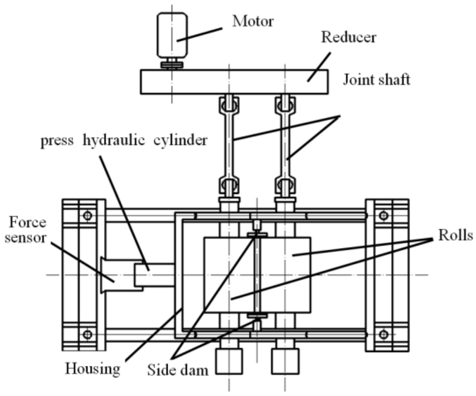
In this paper, a typical cast-rolling roll is taken as an example. The casting rolling pressure and temperature are obtained by experiments. The change rules of the cast-rolling roll profile under different cast-rolling pressure and temperature are simulated by FEM. The change rules of cast-rolling roll profile in the middle, edge marked point and edge under different cast-rolling pressure and temperature are respectively expressed by cube polynomial equations, these equations can be taken as the prediction models of thickness and flatness of cast-rolling plate and strip and provide the basis for the control of thickness and flatness of cast-rolling strip.

2 Structure description of cast-rolling mill and rolls

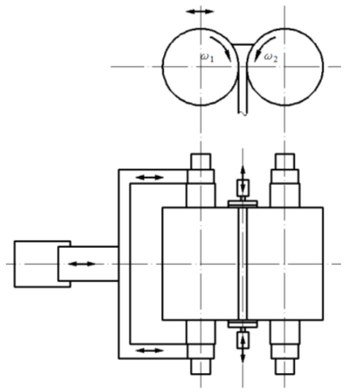
A twin-roll strip cast-rolling mill is shown in Fig.1(a). Roll gap is shown in Fig.1(b). Fig.1(c) is a top view of twin-roll strip cast-rolling mill. In Fig.1, cast-rolling rolls are assembled in a frame and roll gap is sealed by two side dams. Two cast-rolling rolls are respectively driven by the reducer through two connecting shafts. A motor is taken as the power source. Fig.1(d) indicates that two rolls rotate in opposite directions. The left roll can move under the push of the hydraulic cylinder. The cast-rolling pressure can be measured by force sensor at the side of the cylinder. The position of two side dams can be adjusted by two hydraulic cylinders.

(a) Twin roll strip cast-rolling mill

(b) Roll gap



(c)Top view of twin roll strip cast-rolling mill



(d) Front and top view of rolls and gap

Fig. 1. Twin roll strip casting mill

A cast-rolling roll is shown in Fig. 2(a). It contains a roll sleeve shown in Fig.2(b) and a roll core shown in Fig.2(c). The roll core can be divided into two sections, roll core body and roll neck shown in Fig.2(d). There are some water channels shown in Fig.2(e) in the roll core body and neck for cooling the roll to increase the temperature of the roll while cast-rolling.

(a) Roll

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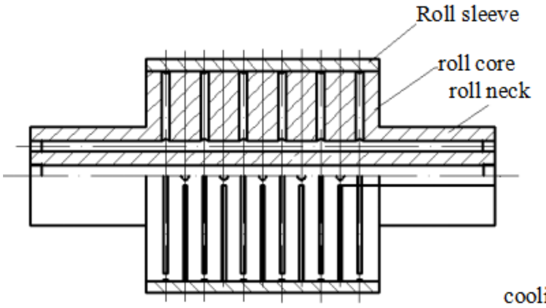
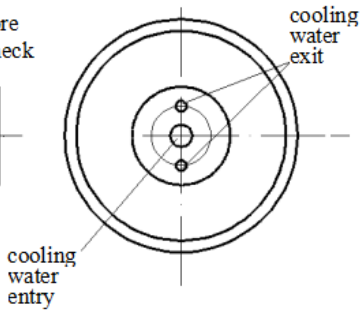
(b) Roll sleeve (c) Roll core



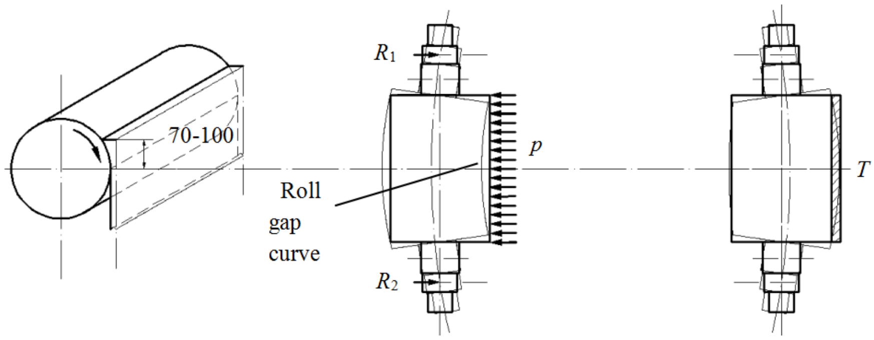


(d) Inner of Roll (e) Left view of roll

Fig. 2. The structure of a cast-rolling roll

During cast-rolling process, the molten liquid metal is poured into the roll gap. Generally, the level of liquid metal is 70~100mm height from the axis plane of two rolls, as shown in Fig.3(a). The cast-rolling roll gap curve is defined as the outer circle generatrix of roll sleeve located on the bottom of roll gap. Normally, the roll gap curve is the overlay or sum of bending deformation shown in Fig.3(b) produced by cast-rolling force and thermal expansion shown in Fig.3(c) caused by higher and uneven temperature distribution on the roll conducted from molted metal. The thermal expansion in the middle part of the roll is larger than those in the two ends of roll due to the different heat dissipation rate.

As shown in Fig.4. The shape of roll gap curve can have a serious impact on the thickness h_0 (Intima-media thickness) and flatness (crown, the difference of thickness in the middle h_0 and that in the edge h_1 marked point, h_0-h_1) of cast-rolling product. The change rules of intima-media thickness and edge marked point can be obtained by FE simulation. Therefore, the effect of casting rolling pressure and temperature on thickness and flatness can be predicted.



(a) Height of melt pool (b) Bending deformation of roll (c) Thermal expansion of roll

Fig. 3. Schematic diagram of cast-rolling zone and roll profiles

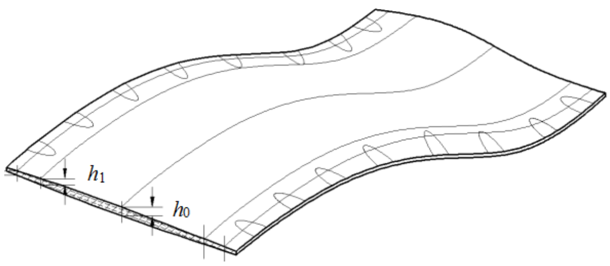


Fig. 4. The thickness and flatness of cast-rolling plate

3 Finite element modeling of a cast-rolling roll

A cast-rolling roll is taken as an example to simulated the effect of casting rolling pressure and roll rolling temperature on roll gap curve. The structure parameters of the cast-rolling roll are shown in Table 1.

Table 1. The parameters of a cast-rolling roll

	External radius (mm)	Internal radium (mm)	Length (mm)	Material
Roll sleeve	300	275	600	CuCrZr alloy
Roll core body	275	——	600	40Cr
Roll neck	110	——	300	40Cr

3.1 Meshing

A 3D finite element model of roll is established by using of the element type of Solid45 on the ANSYS software platform. The cast-rolling zone are meshed zoom-in much because of its large deformation due to the contacting with melted metal and

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higher temperature. The total number of elements of the roll finite element model is 15456, shown as Fig.5.

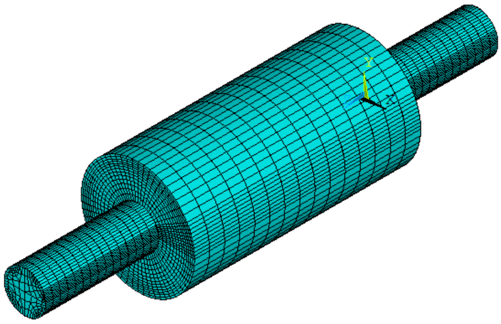

Fig. 5. 3D FE model of the cast-rolling roll

3.2 Boundary conditions

When the interference value of shrink is contracted between roll core is 0.3-0.6mm, the equivalent stress of the outer surface of roll sleeve changes slightly[13]. Therefore, the roll body and roll sleeve are taken as a whole entity when simulating the casting roll profile. After meshing, each roll end surface is completely constrained.

3.2.1 Cast-rolling pressure

The casting rolling force in the experiment is measured by the sensor. The casting rolling pressure is determined by the casting rolling force divided by the number of nodes in the casting rolling zone

3.2.2 Cast-rolling temperature

The temperature field applying on the sleeve is also measured by measurement directly, which is measured by a thermocouple in the cast-rolling zone and an infrared thermometer near the cast-rolling product. Moreover, the cooling water temperature can be measured with a thermometer.

The temperature distribution of roll sleeve is related to the rotation speed of roll. Cast-rolling velocity is usually 20-30m/min. The actual temperature distribution of the roll sleeve considering the effort of roll rotating speed is shown as Fig.6. This result is the same as in the literature [5]. The circumferential temperature values along the outer surface of roll sleeve considering the effort of roll rotating speed are drawn as shown in Fig.7.

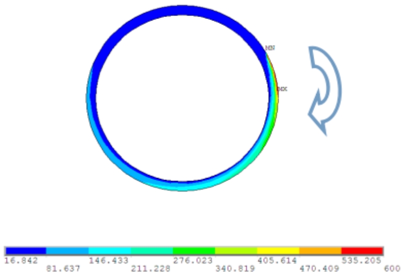

Fig. 6. Temperature distribution of the roll sleeve with a rotate speed

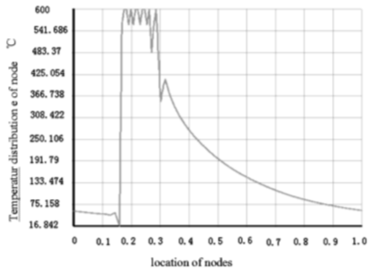

Fig. 7. The temperature values of roll sleeve along outer surface

4 Simulation results of cast-rolling roll gap curve

Based on the above FEM, a group of roll gap curves are obtained by numerical simulation under different cast-rolling pressure and different temperature distributions of the sleeve.

4.1 Pressure profile curves

A group of different cast-rolling pressures 0.64, 1, 0.5, 1.5, 2, 2.5, 3, 3.5, 4, 4.5 and 5MPa under cast-rolling temperature 510℃ are shown in Fig.8.

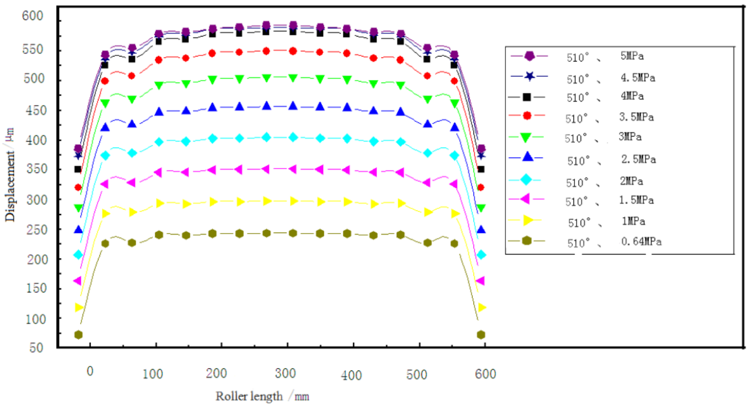

Fig. 8. Bending deformation of roll under different cast-rolling pressures

As shown in figure 8. The results show that the bending deformation of the roll has similar shape at different pressures, and the deformation of the rolls increases with the increase of the casting rolling pressure. The displacement in the middle of the roll sleeve is greater than the displacement at the edge. The displacements difference between two adjacent cast-rolling pressure decreases, and the displacements difference between the middle part and edge increases as the cast-rolling pressure

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increases. In the left edge from 0mm to 40mm and right edge from 560mm to 600mm, the displacement, compared with that in the middle of roll, has a sudden growth. The sudden change of the roll edges displacements may be caused by the sudden change of diameter from roll neck to roll body. For the roll with the length of 600mm, the width of edge should be 40mm to the end, and the edge marked point should be at 120mm. The thickness of product should be the thickness in the middle, 300mm to the end. The crown should be the difference of thickness in the 300mm and that in the 120mm.

The displacements of the roll middle (300mm) under different cast-rolling pressures y_{p300} can be fitted to pressure x_p by a cube polynomial curve and a cube polynomial equation as following equation (1).

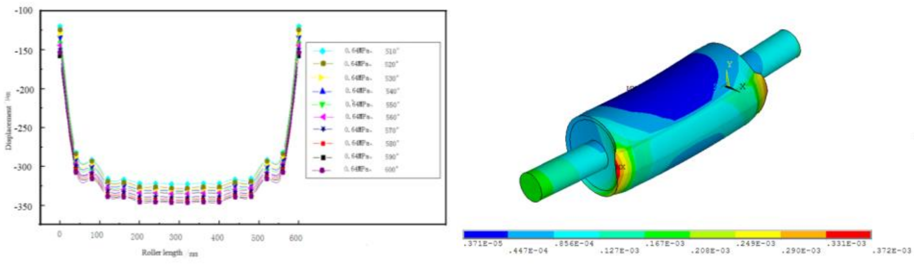
$$y_{p300} = -2.3561x_p^3 + 4.5316x_p^2 + 119x_p + 185.52 \quad (1)$$

In the same way, the thickness in the roll edge marked point y_{p120} can also be fitted to pressure x_p by cube polynomial equations as followings equation (2).

$$y_{p120}=-2.371x_p^3+5.5961x_p^2+109.96x_p+191.3 \quad (2)$$

4.2 Thermal profile curves

Ten groups thermal profile curves under different cast-rolling temperatures of 510℃,520℃,530℃,540℃, 550℃,560℃,570℃,580℃,590℃, and 600℃ are simulated and shown in Fig.9(a). It illustrates that these thermal profile curves are in the same shape under different temperatures, but displacement increases as the cast-rolling temperature increases. The displacements in the middle part of the roll sleeve are larger than those of the edge. The displacements difference between two adjacent cast-rolling temperature decreases, and the displacements difference between the middle part and edge increases as the cast-rolling temperature increases. In the left edge from 0mm to 40mm and right edge from 560mm to 600mm, the displacement, compared with that in the middle of roll, has a sudden growth. The sudden displacements change in the edges of roll may caused by the sudden expansion of outer surface within cast-rolling zone along the axis direction of roll. This phenomenon can be seen from the displacement contour under casting temperature 600℃, as shown in Fig.9(b).



(a) (b)

Fig. 9. The thermal profile curves of the cast-rolling roll and the displacement contour under casting temperature 600℃

The displacements of the roll middle (300mm) y_{T300} can be fitted to temperature x_T by a straight line and a linear equation as following equation (3).

$$y_{T300} = -0.2521x_T - 195.67 \tag{3}$$

In the same way, the displacements of the roll edge marked point y_{T120} can also be fitted to temperature by linear equation as following equation (4).

$$y_{T120} = -0.2515x_T - 187.31 \tag{4}$$

5 Discussion and Prediction of profile curves of the cast-rolling roll

The thickness deviation $\triangle h_{300}$ of cast-rolling products can be predicted by the sum of equation (1) and equation (3), that is shown as following equation (5).

$$\triangle h_{300} = y_{300} = y_{p300} + y_{T300} = -2.3561x_p^3 + 4.5316x_p^2 + 119x_p - 0.2521x_T - 10.15 \tag{5}$$

The crown (h_0-h_1) can be predicted by the sum of equation (2) and equation (4), that is shown as following equation (6).

$$C = \triangle h_{300} - \triangle h_{120} = 0.0149x_p^3 - 1.0645x_p^2 + 9.04x_p - 0.0006x_T - 14.14 \tag{6}$$

For example, if a product is cast-rolled at pressure 5MPa with cast-rolling temperature 600℃, its predicted thickness deviation can be calculated by eq.(5) is -11.56μm. The crown predicted by equation (6) is 5.95μm . Of course, there are other factors that affect the thickness deviation and flatness of cast-rolling strip else. The above models are helpful to predict the the thickness deviation and flatness of products, and further studies and experiments should be carried out gradually.

6 Conclusions

(1) The roll profiles change sharply in the edge of product both under cast-rolling pressure and temperature. For two roll strip cast-rolling mill with a roll of 600mm length, the edge can be determined at 40mm to the end, and should be cut off finally for bad thickness and flatness.

(2) For two roll strip cast-rolling mill with a roll of 600mm length, the thickness and flatness of the section between left edge marked point, 120mm to the left end, and right edge marked point, 480mm to the right end is satisfied.

(3) The thickness deviation and flatness (crown) before cast rolling can be predicted by models developed by FE simulation and fitting.

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