Design of a Kind of Backup Roll Contour Used in Four-High CVC Hot Strip Mill

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The phenomenon of uneven contact pressures between cylindrical backup roll and CVC (Continuously Variable Crown) work roll in four-high hot strip mill has always existed, which can lead to seriously uneven wear of cylindrical backup roll and even spalling defect. In order to obtain an available solution plan for above mentioned problem, a new kind of backup roll contour called reverse CVC backup roll contour is proposed in this paper. Reverse CVC backup roll contour is generated by fitting four cubic chamfer contours and one backup roll surface contour designed by CVC work roll contour. And one roll elastic deformation simulating software coded based on Influence Function Method has been used to calculate and study the contact pressure distributions between CVC work roll and reverse CVC contour backup roll or cylindrical contour backup roll. Compared with cylindrical contour backup roll, contact pressures between CVC work roll and reverse CVC contour backup roll are much smoother without steep peak. Simulating results meet well with data collected from the application field, wear of new reverse CVC contour backup roll is more well-distributed than cylindrical contour backup roll.

KEY WORDS: backup roll contour; CVC work roll; backup roll wear; contact pressure.

1. Introduction

CVC work roll technology1–4) has a great capability of strip shape control. Both upper and bottom CVC work rolls are ground to an identical S-shape and inverted 180 degrees from each other, as a result, a continuously adjustable roll gap profile is obtained by the axial shifting of upper and bottom rolls. So far, CVC work roll technology has been widely used in many hot rolling lines worldwide. At present, cylindrical contour backup roll is still used together with CVC work roll in most of hot finishing mills. However, because of the uneven contact pressure distributions between cylindrical contour backup roll and CVC work roll, seriously uneven wear of cylindrical contour backup roll can easily occur.5) Considering the long changing period of backup roll (3–4 weeks), once backup roll appears seriously uneven wear under complex working conditions, the effect of strip shape control will be greatly affected, as well as the quality of strip surface.5) Meanwhile, there is always extremely large and steep contact pressure peak at the end of cylindrical contour backup roll, which can easily lead to serious wear and even spalling defect for backup roll.7,9) Spalling defect will significantly affect the lifetime of backup roll and production efficiency. Therefore, it is necessary to develop a new kind of backup roll contour to take place of the cylindrical one.

Up to now, many kinds of backup rolls have been proposed to solve the problems encountered in the field. DSR (Dynamic Shape Roll) technology10–12) can realize dynamic adjustment of backup roll. The edge wave and center wave of the strip can be effectively controlled by DSR technology, as well as some strip shape defects of high order. But DSR technology is difficult to be applied in practical production owing to its complicated mechanical structure. VC (Variable Crown) roll,11,13–15) which has an oil chamber filled with high pressure oil between the sleeve and the arbor, can achieve an ideal effect of strip shape control. In order to meet the change of rolling force, the crown of backup roll is changed by changing oil pressure. Nevertheless, the high equipment requirement makes the practical application of VC roll also become difficult. Moreover, ASR (Adjustable Stepped Roll) and VBL (Variable Barrel Length) roll similar to the above mentioned backup rolls also have been proposed.15,16) Stepped backup roll can eliminate the influence of harmful contact zone between backup roll and work roll, but the large stress concentration also exists at the edge of roll.15) Varying contact length backup roll (VCR)17–20) has a special roll contour described by one high order polynomial curve. VCR technology can make the contact length between backup roll and work roll fit to the strip width. So, the harmful contact zone between backup roll and work roll is reduced or even eliminated, the lateral stiffness of loaded gap is improved and the control effect of roll bending is enhanced. But varying contact length backup roll seems to lack coordination when it is used with CVC work roll. On the basis of above introductions, it can easily find that backup roll technology still
needs to be studied further.

Influence function method based on discretization is one of the effective methods to calculate elastic deformation of roll. It is not necessary for influence function method to assume distributions of roll crown, rolling pressure and contact pressure between rolls, so various complicated problems can all be dealt flexibly. K. N. Shohet derived influence functions of roll elastic bending, and the influence function method used to calculate elastic deformation of roll was given definitely. Y. Tozawa et al. further perfected the application of influence function method in calculating the elastic deformation of roll. V. Salganik established the elastic deformation model of four-high mill by using matrix method, and a tool used to optimize strip shape control was provided. Y. L. Liu et al. established a model based on influence function method to study roll deformation in cold rolling and asymmetrical rolling process, as well as the thin strip deformation in cold rolling. In this paper, influence function method is used to study contact pressure distributions between backup roll and work roll.

In this paper, a new kind of backup roll contour called reverse CVC backup roll contour is presented, which is designed to solve the problem of uneven contact pressures between cylindrical backup roll and CVC work roll in four-high mill. The main feature of reverse CVC backup roll contour is that the contour is generated by fitting one roll surface contour and four cubic chamfer contours, and roll surface contour is designed based on CVC work roll contour. Because of good matching with CVC work roll, contact pressures between reverse CVC contour backup roll and CVC work roll distribute more uniformly, meanwhile, a good effect on strip profile control can also be achieved. And the chamfer sections of reverse CVC contour decrease the steep contact pressure peak and reduce or even eliminate the harmful contact zone, which is beneficial to avoid spalling defects and improve the shape control ability. So, the design of reverse CVC backup roll contour will make it have a strong effect of uneven wear control for backup roll.

The paper is arranged as follows. Section 2 introduces configurations and problems of roll contour in the concrete hot rolling line, moreover, specific reverse CVC backup roll contours according to the detailed design philosophy and realistic conditions are provided. In Section 3, a comparative study of the contact pressure distributions between CVC work roll and backup roll with different contours is presented based on influence function method. Section 4 is devoted to the application of reverse CVC backup roll contour. And section 5 lists the main conclusions of the paper.

2. Design of Reverse CVC Backup Roll Contour

2.1. Configurations and Problems of Roll Contour

The research of this paper relies on certain 1780 mm hot strip rolling line in China. As shown in Fig. 1, mills of this hot rolling line include an edge rolling mill (E1), four-high reversible roughing mill (RM) and seven stands of four-high finishing mills (FM). Currently, work rolls of stand 1 to stand 4 in finishing mills (F1–F4) are CVC work rolls with diameters of 760–850 mm, lengths of 2080 mm and shifting ranges of ±120 mm; other finishing mills (F5–F7) are configured with cylindrical work rolls with diameters of 630–700 mm, lengths of 2080 mm and shifting ranges of ±100 mm. And all backup rolls in finishing mills are cylindrical contour rolls, diameters and lengths are 1450–1600 mm and 1780 mm respectively.

Through the long-term tracking research of field, cylindrical contour backup rolls used in finishing mills always occur seriously uneven wear, especially in F1 to F4. And the situation of F4 is more serious than others, the edges of backup roll have seriously concentrative wear. Typical wear contour of cylindrical contour backup roll in F4 is displayed in Fig. 2. This phenomenon is mainly related to non-uniform contact pressure distributions, as well as the influence of centralized work roll shifting positions. In order to solve above problems, reverse CVC backup roll contour primely matching with CVC work roll contour is designed in this paper.

2.2. Design Philosophy of Reverse CVC Backup Roll Contour

Focusing on the seriously uneven wear of cylindrical contour backup roll in F4, reverse CVC backup roll contours were designed. Roll surface contour (no chamfer section) of
reverse CVC contour backup roll was designed according to CVC work roll equivalent contour. And CVC work roll equivalent contour was derived based on CVC work roll contour.

The CVC work roll contour of certain 1780 mm hot rolling line has been shown in Fig. 3. Upper and bottom CVC work roll contours are respectively described as:

\[
y_{ul}(x) = K_1 \times x + K_2 \times x^2 + K_3 \times x^3 + Q \quad (1)
\]

\[
y_{bl}(x) = K_1 \times (L - x) + K_2 \times (L - x)^2 + K_3 \times (L - x)^3 + W \quad (2)
\]

Where \(K_1, K_2, K_3, Q\), and \(W\) are parameters of CVC work roll contour; \(x\) (0 \(\leq\) \(x\) \(\leq\) \(L\)) is the axial coordinate of CVC work roll (from operation side to drive side), mm; \(L\) is the length of CVC work roll, mm.

Upper and bottom CVC work roll equivalent contours derived based on axial shifting of CVC work rolls are expressed as follows:

\[
y_{ul}(x) = K_1 \times (x + s) + K_2 \times (x + s)^2 + K_3 \times (x + s)^3 + Q \quad (3)
\]

\[
y_{bl}(x) = K_1 \times (L - x + s) + K_2 \times (L - x + s)^2 + s \quad (4)
\]

Where \(x\) (0 \(\leq\) \(x\) \(\leq\) \(L\)) is the axial coordinate of CVC work roll, mm; \(s\) is the shifting position of CVC work roll, mm; \(s > 0\) mm is shifting to forward direction; \(s < 0\) mm is shifting to negative direction; \(s = 0\) mm is no shifting.

CVC work roll shifting positions of F4 mainly concentrate in the range of 0–120 mm. In order to greatly match with CVC work roll contour, roll surface contours of reverse CVC contour backup rolls in F4 were designed according to CVC work roll equivalent contours derived at the shifting range of 0 mm \(\leq\) \(s\) \(\leq\) 120 mm. As displayed in Fig. 4, when CVC work roll shifting positions are \(s = 0\) mm, \(s = +50\) mm and \(s = +100\) mm, upper and bottom CVC work roll equivalent contours have been given respectively.

According to the arrangement of work roll and backup roll in finishing mill, lower roll surface contour of upper reverse CVC contour backup roll derived based on upper CVC work roll equivalent contour is expressed by Eq. (5). Because of the symmetry of roll, upper roll surface contour of upper reverse CVC contour backup roll derived by its lower roll surface contour is described as Eq. (6). In the same way, lower and upper roll surface contours of bottom reverse CVC contour backup roll are respectively described as Eqs. (7) and (8).

\[
y_{u1}(x) = K_1 \times (x + s) + K_2 \times (x + s)^2 + K_3 \times (x + s)^3 + Q \quad (5)
\]

\[
y_{u2}(x) = -y_{u1}(x) \quad (6)
\]

\[
y_{b1}(x) = K_1 \times (L - x + s) + K_2 \times (L - x + s)^2 + K_3 \times (L - x + s)^3 + W \quad (7)
\]

\[
y_{b2}(x) = -y_{b1}(x) \quad (8)
\]

Where \(x\) \((L - L_1) / 2 \leq x \leq (L + L_1) / 2\) is the axial coordinate of CVC work roll, mm; \(L_1\) is the length of backup roll, mm.
curves were obtained by fitting roll surface contour and four cubic chamfer contours. Equation (9) is the concrete expression of reverse CVC contour of upper backup roll. As displayed in Fig. 5, concrete reverse CVC contours of upper and bottom backup rolls are presented according to the final fitting parameters.

\[
y(x) = -0.96634 + 6.22620 \times 10^{-3} x - 1.10967 \times 10^{-5} x^2 + 8.80928 \times 10^{-9} x^3 - 3.54672 \times 10^{-12} x^4 + 1.03072 \times 10^{-15} x^5 - 2.69922 \times 10^{-19} x^6
\]  

... (9)

Compared with backup roll surface contours (reverse CVC contour without chamfer section) shown in Fig. 5, reverse CVC backup roll contour generated by fitting roll surface contours and chamfer contours have smaller ups and downs. As a result, the axial shifting of CVC work roll will be easier and the possibility of forming stress concentration is smaller for reverse CVC contour backup roll. Figure 6 displays the assembly drawing of CVC work rolls and reverse CVC contour backup rolls designed based on the CVC work roll equivalent contours derived at the shifting position of +50 mm. The diagram can provide a basis for the further application.

According to the same method, another two reverse CVC backup roll contours of F4 were individually designed based on CVC work roll equivalent contours gained at the shifting positions of 0 mm and 100 mm. Figure 7 shows three reverse CVC contours of upper backup rolls of F4 developed by three different CVC work roll equivalent contours. In the following paragraphs, R-CVC 1, R-CVC 2 and R-CVC 3 respectively represent backup rolls whose reverse CVC contours were designed based on the CVC work roll equivalent contours derived at the shifting positions of 0 mm, +50 mm and +100 mm.

### 3. Performance Analyses of Reverse CVC Backup Roll Contour

In this section, contact pressure distributions between CVC work rolls and R-CVC 1, R-CVC 2, R-CVC 3 or cylindrical contour backup roll have been calculated and studied.

#### 3.1. Study Method

A roll elastic deformation simulating software coded based on influence function method was developed in this paper. The specific calculation process of the simulating program is shown in Fig. 8. \( \varepsilon_1, \varepsilon_2 \) and \( \varepsilon_3 \) are convergence
indices of the roll elastic deformation calculation program. $\varepsilon_1$ is the maximum contact pressure difference of each element in adjacent iterative calculation. $\varepsilon_2$ is the difference between total rolling pressure and its set value. $\varepsilon_3$ is the maximum section configuration difference of the exit strip in adjacent iterative calculation. The selection of convergence indices is very important, unsuitable convergence indices will affect the calculation accuracy and the astringency of whole calculation process. In order to meet the requirement of the calculation accuracy, convergence indices were selected as follows: $\varepsilon_1 = 10^{-4}$ N, $\varepsilon_2 = 10^{-3}$ N and $\varepsilon_3 = 10^{-4}$ mm. Moreover, the flattening constant of roll center was modified by the secant method. And contact pressure distributions and the section configuration of exit strip were respectively modified as follows:

\[ \tilde{q}_i^n = \tilde{q}_i^{n-1} + \alpha \times (\tilde{q}_i^{n-1} - \tilde{q}_i^n) \] ............... (10)

\[ \tilde{h}_i^n = \tilde{h}_i^{n-1} + \beta \times (\tilde{h}_i^{n-1} - \tilde{h}_i^n) \] ............... (11)

Where $n$ is the number of calculation, $I$ and $C$ are symbols of iteration values and calculation values respectively, $\alpha$ and $\beta$ are smoothness indices related to the contact pressure distributions and the section configuration of exit strip for iteration respectively.

### 3.2. Calculation Results

According to the calculation process of roll elastic deformation calculation software shown in Fig. 8, contact pressure distributions between CVC work roll and reverse CVC contour backup roll or cylindrical contour backup roll were calculated under the same rolling condition. The whole calculation process kept all CVC work roll parameters (except for shifting position), backup roll parameters (except for backup roll contour), strip parameters (including entrance thickness and exit thickness etc.) and processing parameters (bending force and temperature etc.) constant. And these basic parameters used in the calculation process are listed in Tables 2, 3 and 4 in detail.

**Table 2.** The parameters of CVC work roll.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter [mm]</td>
<td>800 (760–850)</td>
</tr>
<tr>
<td>Young’s modulus [GPa]</td>
<td>206</td>
</tr>
<tr>
<td>Poisson ratio</td>
<td>0.333</td>
</tr>
<tr>
<td>Centerline spacing of bending cylinder [mm]</td>
<td>2 740</td>
</tr>
<tr>
<td>Length of work roll [mm]</td>
<td>2 080</td>
</tr>
<tr>
<td>Bending force [kN]</td>
<td>700</td>
</tr>
<tr>
<td>Shifting positions [mm]</td>
<td>−120–120</td>
</tr>
</tbody>
</table>

**Table 3.** The parameters of backup roll.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter [mm]</td>
<td>1 500 (1 450–1 600)</td>
</tr>
<tr>
<td>Young’s modulus [GPa]</td>
<td>206</td>
</tr>
<tr>
<td>Poisson ratio</td>
<td>0.333</td>
</tr>
<tr>
<td>Centerline spacing of hydraulic cylinder [mm]</td>
<td>2 740</td>
</tr>
<tr>
<td>Length of backup roll [mm]</td>
<td>1 780</td>
</tr>
</tbody>
</table>

**Table 4.** The parameters of strip.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entrance thickness [mm]</td>
<td>9.7</td>
</tr>
<tr>
<td>Exit thickness [mm]</td>
<td>6.5</td>
</tr>
<tr>
<td>Width [mm]</td>
<td>1 300</td>
</tr>
<tr>
<td>Deformation resistance [GPa]</td>
<td>0.2199</td>
</tr>
<tr>
<td>Temperature [°C]</td>
<td>980</td>
</tr>
</tbody>
</table>

![Fig. 8. Calculation process of roll elastic deformation simulating software.](image)
As displayed in Figs. 9–11, contact pressure distributions between CVC work roll and R-CVC 1, R-CVC 2, R-CVC 3 or cylindrical contour backup roll at different CVC work roll shifting positions have been obtained respectively. Shifting positions include 0 mm, ±50 mm, +100 mm, +120 mm.

3.3. Analysis of Calculation Results

Figures 9–11 have shown that the difference of roll contour design and the change of roll shifting position will cause the difference of contact pressure distributions between rolls. A good design of backup roll contour will result in the uniform contact pressure distributions in the strip rolling process. As shown in Figs. 9–11, the contact pressure distributions of cylindrical contour backup roll are very uneven with obvious contact pressure peaks, especially the large and steep contact pressure peaks in the right side. The uneven contact pressure distributions will lead to seriously uneven wear on cylindrical backup roll, and the calculation results meet well with the actual wear contour displayed in Fig. 2. In addition, the large and steep contact pressure peak appearing at the end of cylindrical roll will generate local stress concentration. And spalling defect is probably caused by the large stress concentration. Compared with cylindrical contour backup roll, contact pressure distributions of reverse CVC contour backup roll are more uniform without steep and large contact pressure peaks. The contact pressure peaks of reverse CVC contour backup roll appear at the contact zone between strip and work roll. So, the harmful contact zone will be reduced or even eliminated.

![Fig. 9](image-url)  
*Fig. 9.* Contact pressure distributions of R-CVC 1 and cylindrical roll at different shifting positions for a)–e) each representative shifting positions and f) all given shifting positions.
In order to furtherly study the performance of each reverse CVC contour, specific contact pressure peaks between CVC work roll and backup rolls with different contours at the work roll shifting positions of 0 mm, ±50 mm, +100 mm, +120 mm have been obtained, which are shown in Table 5. Although the contact pressure peak of each reverse CVC contour backup roll at +120 mm is bigger than that of the cylindrical one, the change of contact pressure peak for each reverse CVC roll is gentler as displayed in Figs. 9–11 and the possibility of forming stress concentration is smaller.

Among reverse CVC contour backup rolls, R-CVC 1 has maximum contact pressure peaks at −50 mm and 0 mm, R-CVC 3 exists maximum contact pressure peaks at +50 mm, +100 mm and +120 mm.

Except for the influence of contact pressure peak, the holistic contact pressure distributions will directly affect the wear of backup roll. So, holistic contact pressure distributions of different backup rolls are furtherly reflected by calculating the standard deviation of contact pressures for each backup roll contour at different CVC work roll shifting positions, which is expressed as:

$$SD_k = \sqrt{\frac{1}{N} \sum_{i=1}^{N} q_k(i) - \frac{1}{N} \sum_{i=1}^{N} q_k(i)}^2$$  \hspace{1cm} (12)

where $SD_k$ is standard deviation of contact pressures at CVC work roll shifting position of $k$, kN/mm; $q_k(i)$ is contact pressure of $i$-th roll element at CVC work roll shifting position of $k$, kN/mm; $N$ is the amount of roll elements.
Table 5. Contact pressure peaks of different contour backup rolls at different shifting positions.

<table>
<thead>
<tr>
<th>Shifting position [mm]</th>
<th>-50</th>
<th>0</th>
<th>+50</th>
<th>+100</th>
<th>+120</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-CVC 1</td>
<td>18.496</td>
<td>18.555</td>
<td>18.488</td>
<td>18.933</td>
<td>19.075</td>
</tr>
<tr>
<td>R-CVC 2</td>
<td>18.428</td>
<td>18.473</td>
<td>18.513</td>
<td>18.938</td>
<td>19.278</td>
</tr>
<tr>
<td>R-CVC 3</td>
<td>18.419</td>
<td>18.372</td>
<td>18.695</td>
<td>19.199</td>
<td>19.335</td>
</tr>
</tbody>
</table>

As shown in Table 6, the standard deviations of contact pressures for each backup roll contour at different CVC work roll shifting positions short for standard deviation in the following paragraphs have been obtained. Standard deviations of R-CVC 1 and R-CVC 2 at different shifting positions are all smaller compared with the cylindrical roll. Although standard deviations of R-CVC 3 at shifting position +50 mm, +100 mm and +120 mm is bigger than that of cylindrical roll, the mean standard deviation value of R-CVC 3 is smaller than cylindrical one. So, it can be obtained that new reverse CVC contour backup rolls are more beneficial to the holistic uniformity of contact pressure distributions. Among reverse CVC contour backup rolls, the mean standard deviation value of R-CVC 1 is smallest, oppositely, R-CVC 3 has the largest mean standard deviation value. Thus, R-CVC 1 will have a more outstanding effect for holistic uniformity of contact pressure distributions.

Based on above calculation results and analyses, reverse CVC contour which is designed to solve the problem of uneven contact pressures between cylindrical backup roll
and CVC work roll in four-high hot strip mill has obtained
the expectant effect. Compared with cylindrical backup
roll, more uniform contact pressure distributions of reverse
CVC contour backup rolls will be more beneficial to con-
trol uneven wear and avoid spalling defects. To balance the
effect between the holistic uniformity of contact pressure
described by standard deviation and contact pressure peak,
R-CVC 2, which not only has the temperate mean standard
development value close to R-CVC 1 but also the temperate
contact pressure peaks, is the better one for further experi-
mental verification in the factory.

4. Application of the Reverse CVC Backup Roll Con-
tour

According to parameters of backup roll contour, R-CVC
2 was ground to a specific shape. Some basic parameters
of R-CVC 2 are listed in Table 7, which all meet require-
ments of the experiment. Finally, R-CVC 2 was successfully
applied to the fourth CVC mill (F4) of certain 1 780 mm
hot strip rolling line and the effect of application was well.
The service time of R-CVC 2 lasted for 26 days. During
the service time of R-CVC 2, the total production capability
was $2.6 \times 10^5$ tons, the major thickness and width specifica-
tions of productions were 1–4 mm and 1 250–1 630 mm
respectively. Although many thin and wide productions
were produced, the production quality kept well. When
cylindrical contour backup rolls were used in F4, the service
time and production capability were generally about 28 days
and $2.0 \times 10^5$ tons respectively. Though rolling mileage by
using R-CVC 2 has been lengthened, the production quality
can also be greatly guaranteed at the same time. So, we can
consider that the wear condition of backup roll surface must
be improved during the rolling process. Basing on the analy-
sis of above application results, the wear of R-CVC 2 after
service were furtherly studied. Material objects of upper and
bottom R-CVC 2 after service have been shown in Fig. 12.
There are not obvious scratches, cracks and spalling defects
on the roll surfaces, and roll surfaces are good.

Calculation contours, grinding contours and wear con-
tours of upper and bottom R-CVC 2 are displayed in Fig.
13. By comparing, it can be easily obtained from diagrams
that the whole contours of upper and bottom R-CVC 2 after
service are kept well, and wear contours are almost close to
grinding contours. In other words, the wear of R-CVC 2 is
more uniform compared with the wear contour of cylindri-
cal contour backup roll shown in Fig. 2. Simulating results
meet well with the wear data collected from the application
field. And the even wear of R-CVC 2 contour is beneficial to
ensure the great and stable control effect of strip profile dur-
ing its service time. But, the left side of upper R-CVC 2 and

<table>
<thead>
<tr>
<th>Shifting position [mm]</th>
<th>−50</th>
<th>0</th>
<th>50</th>
<th>100</th>
<th>120</th>
<th>Mean value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylindrical</td>
<td>2.8930</td>
<td>2.8583</td>
<td>2.0901</td>
<td>2.0886</td>
<td>2.1411</td>
<td>2.4142</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>[kN/mm]</td>
<td>R-CVC1</td>
<td>2.1538</td>
<td>2.1131</td>
<td>1.9174</td>
<td>1.8152</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R-CVC2</td>
<td>2.0843</td>
<td>2.0395</td>
<td>2.0064</td>
<td>2.0562</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R-CVC3</td>
<td>2.0413</td>
<td>2.3910</td>
<td>2.2681</td>
<td>2.6403</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameters</th>
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<th>Bottom roll</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>High chromium steel</td>
<td>High chromium steel</td>
</tr>
<tr>
<td>Diameter of operating side [mm]</td>
<td>1 470.450</td>
<td>1 471.344</td>
</tr>
<tr>
<td>Diameter of middle [mm]</td>
<td>1 471.133</td>
<td>1 471.767</td>
</tr>
<tr>
<td>Diameter of driving side [mm]</td>
<td>1 470.815</td>
<td>1 471.097</td>
</tr>
<tr>
<td>Accuracy of grinding [mm]</td>
<td>±0.01</td>
<td>±0.01</td>
</tr>
<tr>
<td>Accuracy of contour [mm]</td>
<td>±0.001</td>
<td>±0.001</td>
</tr>
</tbody>
</table>

Fig. 12. Material objects of R-CVC 2 for a) upper R-CVC 2 and b) bottom R-CVC 2.
The possibility of forming stress concentration. And shape of backup roll become more well-distributed and decrease without steep peak, which is beneficial to make the wear and reverse CVC contour backup roll are much smoother contact pressure distributions between CVC work roll and cylindrical backup roll in four-high hot strip mill, a new kind of backup roll contour called reverse CVC backup roll is designed by fitting four cubic chamfer contours and one roll surface polynomial curve. And reverse fitting four cubic chamfer contours and one roll surface in four-high hot strip mill, a new kind of backup roll contour called reverse CVC backup roll is more well-distributed and the grinding contour is kept better, so backup roll life will be prolonged. Meanwhile, rolling mileage by using R-CVC 2 has also been lengthened on the condition of keeping product quality well.

5. Conclusions

In order to solve the problem of uneven contact pressures between CVC work roll and cylindrical backup roll in four-high hot strip mill, a new kind of backup roll contour called reverse CVC backup roll contour is proposed.

(1) Reverse CVC backup roll contour is designed by fitting four cubic chamfer contours and one roll surface contour derived based on CVC work roll contour. And reverse CVC backup roll contour is expressed by the sixth-order polynomial curve.

(2) Compared with cylindrical contour backup roll, contact pressure distributions between CVC work roll and reverse CVC contour backup roll are much smoother without steep peak, which is beneficial to make the wear of backup roll become more well-distributed and decrease the possibility of forming stress concentration. And shape control ability can be improved because of the reduction or elimination of the harmful contact zone for reverse CVC contour backup roll.

(3) The application of reverse CVC backup roll contour has obtained the expectant effect, which is in good agreement with the simulating results. Compared with cylindrical contour backup roll, the wear of R-CVC 2 is more well-distributed and the grinding contour is kept better, so backup roll life will be prolonged. Meanwhile, rolling mileage by using R-CVC 2 has also been lengthened on the condition of keeping product quality well.

Acknowledgements

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