Integrated Effect of Technology Factors on Thickness Difference along the Length of Hot-Rolled Strips

V. A. Nikolaev, A. G. Vasilyev

Zaporizhzhya National Technical University
64 Zhukovskiy St., Zaporizhzhya, 69063, Ukraine

The effect of slab temperature and thickness prior to roughing mill group, rolling rate in the last stand of roughing group and front tension value in the first stands of finishing train on the lengthwise gage interference is researched. Obtained calculation results enable to consider the effect of technological factors considered above when improving the wide strip rolling technological process.

Keywords: ROLLING, TEMPERATURE, SLAB, STRIP, ROLLING RATE, ROUGHING MILL GROUP, FRONT TENSION

Introduction

Thickness stability along the length of hot-rolled strips is caused by mill type and applied equipment. On many hot-strip mills the level of production method ensures possibility of rolling strip less than 2.0 mm thick with required precision and mechanical properties [1-3]. In most cases, this refers to wide thin strip production on casting-rolling modules, in which preheating furnaces prior to the finishing mill group enable not only to raise temperature but also to reduce temperature gradient almost to zero along the length of thin slabs and minimum lengthwise gage interference by 97.5-98 % of finished strip length.

On broad-strip mills with a traditional strip rolling practice from thick slabs (> 150 mm) decrease of lengthwise gage interference of finished strips, in particular, bottom end thickening, ensures application of intermediate rewinders (Coilbox) on the intermediate table section between the roughing mill group and finishing train. Application of intermediate rewinder reduces the temperature gradient of hot-rolled breakdown along the length at the entry in the first stand of finishing train to \( \Delta t_e \approx 10-30 \, ^\circ\text{C} \) and total thickening of bottom end by \( \delta h_e = 0.07-0.12 \, \text{mm} \). At piece rolling of strips on casting-rolling module and hot-rolling broad-strip mill, the front and bottom ends are drawn without tension which is a reason of thickening, especially on the back end section 30-45 m long [4, 5]. Lap welding of several (6-15 pieces) intermediate hot-rolled breakdown prior to finishing train, as on three hot-rolling broad-strip mills in Japan, creates conditions for infinite rolling of lengthened strip where there is no effect of back tension only on the last hot-rolled breakdown. However, there is still temperature gradient effect on strip gage along the length of each hot-rolled breakdown in the "endless" strip. Roll acceleration is an effective method for compensation of temperature gradient effect on strip gauge along the length. But no back tension in this process leads to significant thickness difference on this section [5]. In view of mentioned above, estimation of effect of various factors which are possible to change in the current process of hot-rolling broad-strip mill on lengthwise gage interference is of scientific and practical interest. These factors are as follows: slab temperature and thickness prior to roughing mill group, rolling rate in the last stand of roughing mill group and front tension value in the first stands of finishing train [4, 8].

Results and Discussion

The calculations are carried out as applied to hot-rolling broad-strip mill 1680 considered in work [6]. In the roughing mill group consisting of four-high stand semi-continuous rolling process is accomplished by: OK – stand No. 1, stands No. 2, 3; stands No. 3, 4. Hot-rolled breakdown goes to stand No. 2 after stand No. 1, further it goes from
stand No. 4 into intermediate table at the rate \( v_4 \approx 2.2 \text{ km/s} \). There are six stands with the maximum work roll diameter \( D = 620 \text{ mm} \) in the finishing train, roll rate in the finishing stand No. 10 is \( v_{10} \approx 9.2 \text{ km/s} \). At strip rolling \( h = 2.5 \times 1250 \text{ mm} \) from hot-rolled breakdown 28 mm thick the bottom end rate at the entry in the first stand of finishing train (stand No. 6) is \( v_{3en} \approx 1.03 \text{ km/s} \).

Calculations are performed at slab temperatures, °C: 1165 (base), 1180 and 1200; slab thickness \( H_{sl}, \text{ mm} \): 165 (base) and 180. In the last stand of roughing mill group (stand 4) the following high-speed regime is used:
- rolling (length \( L_r \approx 54 \text{ m} \)) at the constant rate \( v_4 = 2.2 \text{ km/s} \) (base);
- rolling of fast-head section of intermediate hot-rolled breakdown is carried out at the rate \( v_4 \approx 2.2 \text{ km/s} \), and back end at the exit from stand No. 3 \( \approx 25 \text{ m} \) long at the rate \( v_{3en} = 1.0, 1.5 \text{ and } 2.2 \text{ km/s} \).

In the finishing train when rolling last three meters of hot-rolled breakdown in stand No. 5 we applied front tension \( \sigma_f = 15; 40 \text{ and } 60 \text{ N/mm}^2 \). Prior to exit of the bottom end from stand No. 6 we also applied front tension \( \sigma_f = 15; 40 \text{ and } 60 \text{ N/mm}^2 \). Similarly, we rolled the bottom end in stand No. 7. Strip temperature is computed by formulas [5, 7], rolling force and thickness difference of strip in all stands are computed according to models suggested in works [7, 8]. The results of calculations are illustrated in Figure 1-3 and Table 1. The key parameters are presented in Figure 1 under base conditions of rolling \( (v_4 = 2.2 \text{ km/s}) \). In the roughing mill group, rolling temperature drops from \( t_{sl} = 1165 \text{ to } 1083 \text{ °C} \) (front end), i.e. by 82 °C. Near stand No. 5 of finishing train the front end temperature drops to \( t = 992 \text{ °C} \) (Figure 1a), and temperature gradient grows from \( \Delta t = 10 \text{ °C} \) after stand No. 4 to \( \Delta t_{fr} \approx 74 \text{ °C} \) (Figure 1c).

Thus, the temperature gradient along the length of intermediate hot-rolled breakdown increases to \( \Delta t = 78 \text{ °C} \) at \( t_{sl} = 1180 \text{ °C} \) and to \( \Delta t_{fr} = 82 \text{ °C} \) at \( t_{sl} = 1200 \text{ °C} \) (\( t_{sl} \) - slab temperature prior to the first stand of roughing mill group). The temperature in stand No. 10 grows from \( t_{10} = 903 \text{ °C} \) (\( t_{sl} = 1165 \text{ °C} \)) to \( t_{13} = 913 \text{ °C} \) at \( t_{sl} = 1200 \text{ °C} \). Increase in slab thickness to \( H_{sl} = 180 \text{ mm} \) (\( t_{sl} = 1165 \text{ °C} \)) increases temperature gradient along the length of intermediate hot-rolled breakdown prior to stand No. 5 and strip temperature (front end) in stand No. 10 as at slabbing with thickness \( H_{sl} = 165 \text{ mm} \) and temperature \( t_{sl} = 1200 \text{ °C} \). Increase in slab thickness to \( H_{sl} = 180 \text{ mm} \) (\( t_{sl} = 1165 \text{ °C} \)) results in increase of rolling force in the roughing mill group by 8-13 % (\( h_r = 28 \text{ mm} \)) and reduces rolling force in finishing train by 1.5-2 % (Figure 1b).

**Figure 1.** Change of front end temperature (a) in hot-rolling broad-strip mill stands, rolling forces on the front end (b) in stands and temperature gradient along the length of strip (c) prior to stands I-X \( (H_{sl} = 165 \text{ mm}) \). Slab thickness \( H_{sl} \text{ mm} \): 1 - 165; 2 - 180. Base rolling regime \( (v_4 = 2.2 \text{ km/s}) \) (3 - rolling on the intermediate table)
Data on the effect of back section braking action in stand No. 4 at the rate \( v_{4r} = 2.2 \text{ km/s} \) are presented in Figure 2 and Table 1. The degree of hot-rolled breakdown rate change is expressed as a ratio \( v_{43} / v_{4r} \) (\( v_{43} - \) bottom end rate). As shown in Figure 2a, with decrease of relative speed \( v_{43} / v_{4r} \) the temperature of bottom end after the fourth stand (1) and prior to stand No. 5 (2) considerably drops at any slab temperature. However, temperature gradient along the length of intermediate hot-rolled breakdown prior to stand No. 5 (Figure 2b) with drop of bottom end relative speed is essentially diminished. At \( t_{d} = 1165 \ ^\circ\text{C} \) and \( H_{d} = 165 \ \text{mm} \) as compared to base option (\( v_{43} / v_{4r} = 1.0 \)) at \( v_{43} / v_{4r} = 0.455 \) the temperature gradient along the length of breakdown dropped from \( \Delta t_{5g} = 74 \ ^\circ\text{C} \) to \( \Delta t_{5g} = 43 \ ^\circ\text{C} \), i.e. in 1.72 times. Decrease of temperature gradient under these rolling conditions is caused by increase of front end transportation time to stand No. 5. Similar change \( \Delta t = \Phi (v_{43} / v_{4r}) \) is observed at \( t_{d} > 1165 \ ^\circ\text{C} \). However, at \( v_{43} / v_{4r} < 1.0 \) absolute temperature of the front end decreases. So, for curve 2 (Figure 2a) at \( v_{43} / v_{4r} = 1.0 \) \( t_{3k} = 918 \ ^\circ\text{C} \), and at \( v_{43} / v_{4r} = 0.455 \) \( t_{3k} = 888 \ ^\circ\text{C} \) (prior to stand No. 5) (difference 30 \(^\circ\text{C}\)). In stand No. 10 temperature difference drops to 12 \(^\circ\text{C}\) (strip temperatures are 889 and 877 \(^\circ\text{C}\), respectively).

Slab temperature raise increases temperature gradient (Figure 2b), but simultaneously reduces rolling force (Figure 2c) due to decrease of metal flow stress and normal contact stresses in the deformation zone. Using slabs with temperature \( t_{sl} = 1200 \ ^\circ\text{C} \) helps reduce power parameters of rolling by 4-6 %. However, slab temperature growth leads to simultaneous increase of longitudinal gage interference \( \delta h \) after stand No. 10 irrespective of parameter value \( v_{43} / v_{4r} \) (Figure 2d). Thus with decrease of bottom end relative speed to \( v_{43} / v_{4r} = 0.455 \) (\( v_{43} = 1.0 \text{ km/s} \)) the bottom end thickening \( \delta h \) is significantly reduced due to temperature gradient decrease prior to stand No. 5 (Figure 2b). So, at \( H_{d} = 165 \ \text{mm} \) and \( t_{d} = 1165 \ ^\circ\text{C} \) bottom end thickening in stand No. 10 decreases from \( \delta h = 0.213 \ \text{mm} \) (\( v_{43} / v_{4r} = 1.0 \)) to \( \delta h = 0.136 \ \text{mm} \) (\( v_{43} / v_{4r} = 0.455 \)).

![Figure 2](image-url)  
*Figure 2. Change of rolling parameters depending on ratio \( v_{43} / v_{4r} \): temperature of back breakdown (a), temperature gradient along the length of breakdown prior to stand No. 5 (b), rolling force of front end in stand No. 5 (c); bottom end thickening after stand No. 10 (d). Temperature of bottom end after stand No. 4 (1) and prior to stand No. 5 (2). Slab temperature, \(^\circ\text{C}\): 3 - 1165; 4 - 1180; 5 – 1200*
Figure 3. Change of lengthwise gage interference depending on $\Delta t_{5g}$ (a) and lengthwise nonuniform gage interference $\delta h_r$ (b) in stand No. 10 depending on front tension $\sigma_1$ (slab thickness $H_{sl}$, mm): 1 - 165; 2 - 180 ($v_{41}/v_{41} = 0.455$, $t_{sl} > 1165 ^\circ C$). Scale $\Delta t_{5g}$ - for "a", scale $\sigma_1$ - for "b"

Table 1. Hot rolling parameters of 08kp steel strip 2.5×1250 mm. Slab thickness $H_{sl} = 165$ mm, reduction in scalebreaker 20 mm

<table>
<thead>
<tr>
<th>Rolling parameters</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>$h_0$, mm</td>
<td>95</td>
<td>62</td>
<td>41</td>
<td>28</td>
<td>16.0</td>
<td>9.0</td>
<td>6.0</td>
<td>4.0</td>
<td>3.1</td>
<td>2.5</td>
</tr>
<tr>
<td>$t_i$, °C</td>
<td>1163/</td>
<td>1143/</td>
<td>1115/</td>
<td>1083/</td>
<td>992/</td>
<td>984/</td>
<td>967/</td>
<td>952/</td>
<td>928/</td>
<td>903/</td>
</tr>
<tr>
<td>$t_{i+1}$, °C</td>
<td>1146/</td>
<td>1118/</td>
<td>1084/</td>
<td>992/</td>
<td>979/</td>
<td>971/</td>
<td>955/</td>
<td>941/</td>
<td>917/</td>
<td>-</td>
</tr>
<tr>
<td>$P_i$, MN</td>
<td>16.29/</td>
<td>14.85/</td>
<td>10.55/</td>
<td>11.31/</td>
<td>14.98/</td>
<td>15.5/</td>
<td>10.87/</td>
<td>10.67/</td>
<td>6.65/</td>
<td>6.21/</td>
</tr>
<tr>
<td>$\delta h_r$, mm</td>
<td>0.06</td>
<td>0.199</td>
<td>0.12</td>
<td>0.109</td>
<td>2.395</td>
<td>1.123</td>
<td>0.609</td>
<td>0.391</td>
<td>0.271</td>
<td>0.213</td>
</tr>
<tr>
<td>--------------------</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rolling parameters</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>$h_0$, mm</td>
<td>95</td>
<td>62</td>
<td>41</td>
<td>28</td>
<td>16.0</td>
<td>9.0</td>
<td>6.0</td>
<td>4.0</td>
<td>3.1</td>
<td>2.5</td>
</tr>
<tr>
<td>$t_i$, °C</td>
<td>1163/</td>
<td>1143/</td>
<td>1115/</td>
<td>1083/</td>
<td>992/</td>
<td>984/</td>
<td>967/</td>
<td>952/</td>
<td>928/</td>
<td>903/</td>
</tr>
<tr>
<td>$t_{i+1}$, °C</td>
<td>1116/</td>
<td>1118/</td>
<td>1084/</td>
<td>931/</td>
<td>926/</td>
<td>926/</td>
<td>915/</td>
<td>907/</td>
<td>887/</td>
<td>-</td>
</tr>
<tr>
<td>$P_i$, MN</td>
<td>16.29/</td>
<td>14.85/</td>
<td>10.55/</td>
<td>11.31/</td>
<td>17.75/</td>
<td>18.16/</td>
<td>12.42/</td>
<td>11.92/</td>
<td>7.37/</td>
<td>6.78/</td>
</tr>
<tr>
<td>$\delta h_r$, mm</td>
<td>0.06</td>
<td>0.199</td>
<td>0.12</td>
<td>1.205</td>
<td>2.302</td>
<td>0.488</td>
<td>0.076</td>
<td>0.107</td>
<td>0.096</td>
<td>0.094</td>
</tr>
</tbody>
</table>

*) numerator – front end; denominator – bottom end; $t_{i+1}$ – temperature prior to following stand

It is shown in Figure 3a that with temperature gradient drop $\Delta t_{5g}$ there is a linear decrease of bottom end thickening $\delta h_r$ in stand No. 10 which corresponds to data obtained previously [4]. Slab thickness increase has a small effect on bottom end thickening at $\Delta t_{5g} = $ const. However, at $v_{43}/v_{4s} = 1.0$ temperature gradient along the length of strip in stand No. 10 is positive $\Delta t_{10g} = 18 ^\circ C$ ($H_{sl} = 165$ mm, $t_{sl} = 1165 ^\circ C$), at $v_{43}/v_{4s} = 0.455$ temperature gradient of strip in stand No. 10 is negative $\Delta t_{10g} = -2 ^\circ C$. The similar change $\Delta t_{10g}$ is observed at increase of slab temperature and
thickness. But slab thickness increase to H = 180 mm promotes some lowering of temperature gradient (to $\Delta t_{10g} = -3 \, ^\circ C$). The bottom end temperature is a little more than that of the front end which is favorable for bottom end thickness.

**Conclusions**

Analysis of effect of technology factors strip gage along the length showed:

- slab temperature raise from $t = 1165$ to $1200 \, ^\circ C$ reduces rolling force by 4-6 % on all stands of continuous mill but increases thickness difference of finished strip bottom end a little.

- decrease of rolling speed of bottom end section in the last stand of roughing mill group stipulates drop of temperature gradient along the length of intermediate hot-rolled breakdown. At ratio $v_{43} / v_{4r} = 0.455$ ($v_{4r} = 2.2 \, km/s$, $v_{43} = 1.0 \, km/s$) temperature gradient drops $\Delta t_{5g}$ from 74 to 43 $^\circ C$ ($H_{sl} = 165 \, mm$, $t_{sl} = 1165 \, ^\circ C$), i.e. in 1.72 times. However, this results in increase of rolling force in stand No. 4 by 40 % (to 15.87 MN) and in stand No. 5 by 19 % on the front end and by 6.5 % on the bottom end, i.e. momentary load increases from 26.11 to 27.8 MN. Drop of temperature gradient along the length of intermediate hot-rolled breakdown ensures decrease of gage difference of the bottom end from $\delta h_4 = 0.213 \, mm$ to $\delta h_5 = 0.136 \, mm$, i.e. in 1.57 times.

- increase of front tension in the bottom end prior to exit from stands No. 5-7 (at $H_{sl} = 165 \, mm$, $t_{sl} = 1165 \, ^\circ C$ and $v_{43} / v_{4r} = 0.455$) allows reducing thickness increment of bottom end to 0.087-0.094 mm at simultaneous lowering of rolling force.

Obtained results of calculations enable to consider the effect of observed technology factors in the process of wide strip rolling advance.

**References**


* Published in Russian
** Published in Ukrainian

Received November 26, 2010

**Комплексное влияние технологических факторов на приращение толщины по длине горячекатаных полос**

Николаев В.А., Васильев А.Г.

Приведены результаты теоретических исследований по влиянию на продольную разнотолщинность полос температуры и толщины сляба перед черновой группой клетей, скорости прокатки в последней клети черновой группы и величины переднего натяжения в начальных клетях чистовой группы. Полученные результаты расчетов позволяют учитывать влияние рассмотренных технологических факторов при совершенствовании технологического процесса прокатки широких полос.