UDC 621.771.(0.75.8)

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 $\Delta t_r \approx$ 10-30 °C and total thickening of bottom end by δh_s = 0.07-0.12 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 km/s. There are six stands with the maximum work roll diameter D = 620 mm in the finishing train, roll rate in the finishing stand No. 10 is $v_{10} \approx$ 9.2 km/s. At strip rolling h = 2.5×1250 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 $v_{5en} \approx 1.03$ km/s.

Calculations are performed at slab temperatures, °C: 1165 (base), 1180 and 1200; slab thickness H_{sl}, mm: 165 (base) and 180. In the last stand of roughing mill group (stand 4) the following high-speed regime is used:

- rolling (length $L_r \approx 54$ m) at the constant rate $v_4 = 2.2$ km/s (base);
- rolling of fast-head section of intermediate hot-rolled breakdown is carried out at the rate $v_4 = 2.2$ km/s, and back end at the exit from stand No. 3 ≈ 25 m long at the rate $v_{43} = 1.0$, 1.5 and 2.2 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 and 60 N/mm^2. Prior to exit of the bottom end from stand No. 6 we also applied front tension $\sigma_f = 15$; 40 and 60 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 ($v_4 = 2.2$ km/s). In the roughing mill group, rolling temperature drops from $t_{sl} = 1165$ to 1083 °C (front end), i.e. by 82 °C. Near stand No. 5 of finishing train the front end temperature drops to t = 992 °C (**Figure 1a**), and temperature gradient grows from $\Delta t_r = 10$ °C after stand No. 4 to $\Delta t_{5r} \approx 74$ °C (**Figure 1c**).

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

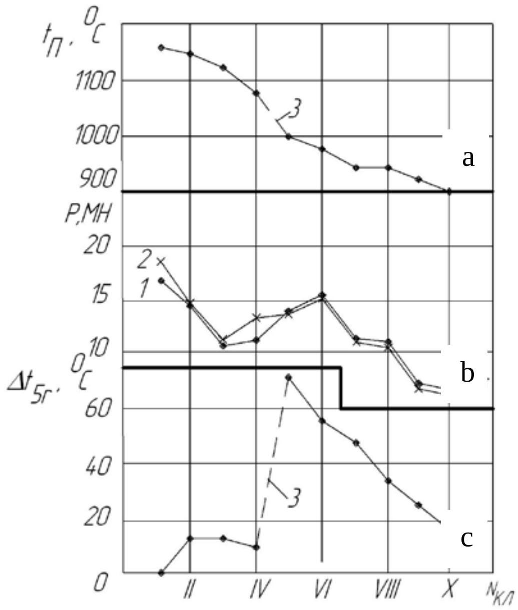

Figure 1. Change of front end temperature (*a*) in hot-rolling broad-strip mill stands, rolling forces on the front end (*b*) in stands and temperature gradient along the length of strip (*c*) prior to stands I-X (H_{sl} = 165 mm). Slab thickness H_{sl} mm: 1 - 165; 2 - 180. Base rolling regime ($v_4 = 2.2$ 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 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_{sl} = 1165 °C and H_{sl} = 165 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 Δt_{5g} = 74 °C to Δt_{5g} = 43 °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 $\Delta t_r = \Phi$ (v_{43} / v_{4r}) is observed at t_{sl} > 1165 °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 °C, and at v_{43} / v_{4r} = 0.455 t_{3K} = 888 °C (prior to stand No. 5) (difference 30 °C). In stand No. 10 temperature difference drops to 12 °C (strip temperatures are 889 and 877 °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 °C helps reduce power parameters of rolling by 4-6 %. However, slab temperature growth leads to simultaneous increase of longitudinal gage interference δh_s after stand No. 10 irrespective of parameter value v_{43} / v_{4s} (**Figure 2d**). Thus with decrease of bottom end relative speed to v_{43} / v_{4s} = 0.455 (v_{43} = 1.0 km/s) the bottom end thickening δh_s is significantly reduced due to temperature gradient decrease prior to stand No. 5 (**Figure 2b**). So, at H_{sl}= 165 mm and t_{sl} = 1165 °C bottom end thickening in stand No. 10 decreases from δh_s = 0.213 mm (v_{43} / v_{4s} = 1.0) to δh_s = 0.136 mm (v_{43} / v_{4s} = 0.455).

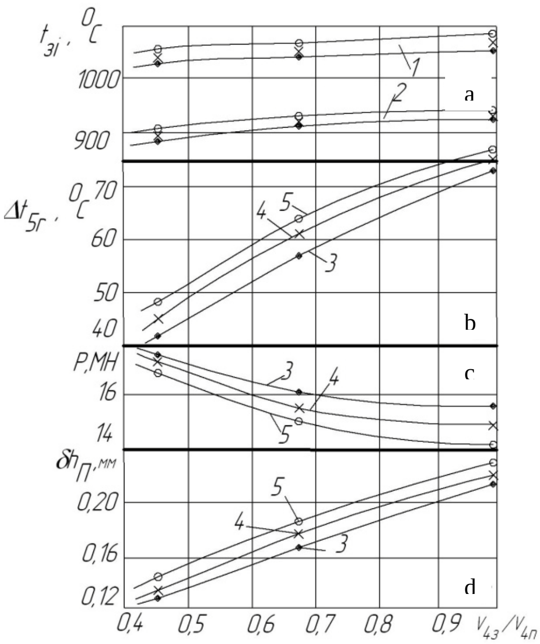

Figure 2. Change of rolling parameters depending on ratio v_{43} / v_{4r}: temperature of back breakdown (*a*), temperature gradient along the length of breakdown prior to stand No. 5 (*b*), rolling force of front end in stand No. 5 (*c*); bottom end thickening after stand No. 10 (*d*). Temperature of bottom end after stand No. 4 (1) and prior to stand No. 5 (2). Slab temperature, °C: 3 - 1165; 4 - 1180; 5 – 1200

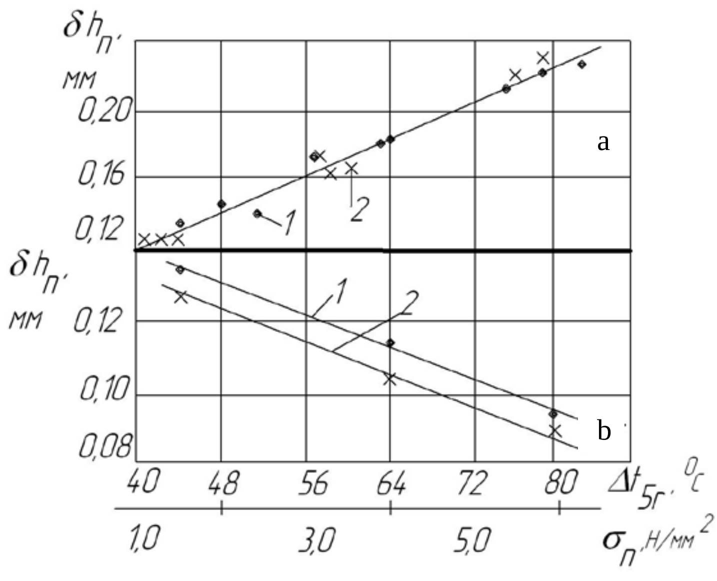

Figure 3. Change of lengthwise gage interference depending on Δt_{5g} (*a*) and lengthwise nonuniform gage interference δh_r (*b*) in stand No. 10 depending on front tension σ_f (slab thickness H_{sl}, mm): 1 - 165; 2 - 180 ($v_{43} / v_{4П}$ = 0.455, t_{sl}> 1165 °C). Scale Δt_{5g} - for "a", scale σ_f - for "b"

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

Rolling parameters	Stand No.*									
	1	2	3	4	5	6	7	8	9	10
Base option at t_{sl} = 1165 °C, v_4 = 2.2 m/s, σ_s = 15 N/mm^2										
h_i, mm	95	62	41	28	16.0	9.0	6.0	4.0	3.1	2.5
t_i, °C	1163/ 1157	1143/ 1130	1115/ 1103	1083/ 1073	992/ 932	984/ 938	967/ 932	952/ 926	928/ 908	903/ 889
t_{i+1}, °C	1146/ 1133	1118/ 1106	1084/ 1074	992/ 918	979/ 923	971/ 928	955/ 922	941/ 916	917/ 899	_
P_i, MN	16.29/ 16.50	14.85/ 15.56	10.55/ 10.93	11.31/ 11.69	14.98/ 26.11	15.5/ 20.18	10.87/ 13.76	10.67/ 12.49	6.65/ 7.89	6.21/ 7.0
δh_r, mm	0.06	0.199	0.12	0.109	2.395	1.123	0.609	0.391	0.271	0.213
Experimental option at t_{sl} = 1165 °C, v_{4s} = 2.2 m/s, v_{43} = 1.0 m/s, σ_s = 60 N/mm^2										
h_i, mm	95	62	41	28	16.0	9.0	6.0	4.0	3.1	2.5
t_i, °C	1163/ 1157	1143/ 1130	1115/ 1103	1083/ 1031	937/ 903	937/ 912	926/ 907	917/ 901	896/ 883	875/ 865
t_{i+1}, °C	1116/ 1133	1118/ 1106	1084/ 1038	931/ 886	926/ 894	926/ 903	915/ 897	907/ 892	887/ 875	_
P_i, MN	16.29/ 16.50	14.85/ 15.56	10.55/ 10.93	11.31/ 15.87	17.75/ 27.8	18.16/ 20.11	12.42/ 13.19	11.92/ 12.76	7.37/ 7.97	6.78/ 7.16
δh_s, mm	0.06	0.199	0.12	1.205	2.302	0.488	0.076	0.107	0.096	0.094

∗) 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 Δt_{5g} there is a linear decrease of bottom end thickening δh_s in stand No. 10 which corresponds to data obtained previously [4]. Slab thickness increase has a small effect on bottom end thickening at Δt_{5g} = const. However, at v_{43} / v_{4s} = 1.0 temperature gradient along the length of strip in stand No. 10 is positive - Δt_{10g} = 18 °C (H_{sl} = 165 mm, t_{sl} = 1165 °C), at v_{43} / v_{4s} = 0.455 temperature gradient of strip in stand No. 10 is negative Δt_{10g} = -2 °C. The similar change Δt_{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 Δt_{10g} = -3 °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 °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 Δt_{5r} from 74 to 43 °C (H_{sl} = 165 mm, t_{sl} = 1165 °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 δh_4 = 0.213 mm to δh_s = 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 °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

1. L.A. Nikitina, B.N. Matveev. *Novosti Chernoy Metallurgii za Rubezhom*, Moscow, JSC "Chermetinformatsiya", 2001, No. 5, pp. 3-29.*
2. Yu.F. Tarasevich. *Proizvodstvo Prokata*, 1999, No. 8, pp. 48-58. *
3. V.N. Khloponin. *Proizvodstvo Prokata*, 2001, No. 8, pp. 14-20. *
4. K.N. Tkalich, Yu.V. Konovalov. *Tochnaya Prokatka Tonkoh Polos*, Moscow, Metallurgiya, 1972, 176 p. *
5. Yu.D. Zheleznov. *Staticheskie Issledovaniya Tochnosti Tonkolistovoy Prokatki*, Moscow, Metallurgiya, 1974, 240 p. *
6. Yu.V. Konovalov, A.L. Ostapenko, V. I. Ponomarev. *Raschet Parametrov Listovoy Prokatki*, Reference Book, Moscow, Metallurgiya, 1986, 430 p. *
7. V.O. Nikolaev, V.L. Masur. *Vyrobnytstvo Ploskogo Prokatu*, Zaporizhzhya, Zaporizhzhya State Engineering Academy, 2010, 320 p. **
8. V.A. Nikolaev, D.A. Matyushenko. *Metal i Lityo Ukrainy*, 2007, No. 8, pp. 20-22. *

* 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.