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Efficiency of Metal Deformation in Tension Roll Passes

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A new expression for definition rolling efficiency in different roll sequences passes accounting roll passes shape influence and correlation between contact resistance in cross and longitudinal direction was obtained. It was determined that the smallest coefficient of effectiveness takes place in rolling sectional bars with free spreading and it rises with increasing of roll pass walls inclination angle.

Keywords: ROLLING OF SECTIONAL METAL, BROADENING, ROLL PASS, DEFORMATION EFFICIENCY

Introduction

During rolling sectional bars different tension roll passes are used, forming such sequences: diamond - square, oval - square, oval - ribbed oval, oval - circle [1-4]. Deformation of metal in each roll pass is uneven in its width and maximum value of the lengthening coefficient and deformation efficiency caused by the ratio of the size and shape of the billet and roll pass. However, the maximum value of cobbing and lengthening coefficient are determined in addition to all other factors, the value of spreading required for complete filling the width of the roll pass. In this case, the smaller is the physical spreading of metal, the more efficient is the process of metal rolling.

Results and Discussion

In order to evaluate the efficiency of form changing of the strip in passes different dependences are used, among which the most appropriate we consider dependence [3]

$$k_e = 1 - \ln\beta / \ln 1/\eta \,, \qquad (1)$$

where k_e - efficiency coefficient; $1/\eta$ - average coefficient of altitude deformation; β - average coefficient of metal cobbing

$$1/\eta = H/h\,;\; \beta = b/B \qquad (2)$$

H and h – average thickness of the strip before and after rolling, B and b - average values of the strip width before and after rolling.

Taking into account the known approximation we can write expression (1) as

$$k_e = 1 - \frac{\Delta b_{av}}{\Delta h_{av}} \cdot \frac{h_{av}}{B_{av}}\,, \qquad (3)$$

where Δh_{av} and Δb_{av} - average cobbing and spreading values; h_{av} and B_{av} - average values of width and contact surface in the deformation zone of the roll pass. Parameters Δh_{av} and Δb_{av} for tension roll passes can be determined from papers [4-6], in which theoretically based models, confirmed by experimental data [7] are presented. The average value of spreading during metal deformation in the roll passes is determined from the expression [4, 6]

$$\Delta b_{av} = \frac{\Delta h_{av} \cdot B_{av} / h_{av}}{1 + C_f \cdot \frac{B_{av}}{l_d}(1 + tg\varphi / f_b)}\,, \qquad (4)$$

where l_d - weighted average of arc length of the contact; φ - average inclination angle of the roll pass walls; f_b - coefficient of flow resistance of metal at the contact surface in the transverse direction; C_f - coefficient reflecting the ratio of flow resistance of metal on the contact in the transverse and longitudinal directions $(C_f = f_b / f$; f - friction coefficient in the longitudinal direction).

Solving equation (3) and (4), we obtain

$$k_e = 1 - \frac{1}{1 + C_f \cdot \frac{B_{av}}{l_d}(1 + tg\varphi / f_b)} \qquad (5)$$

From (5) it follows that the efficiency coefficient of the strip formation in the roll pass increases with increasing the ratio B_{av} / l_d, inclination angle φ of the roll pass walls and coefficient C_f.

For the numerical solution of (5) first of all we define weighted average cobbing and arc length of the contact. The following formulae for the calculation of the parameters appearing in the expression (5) are taken from papers [4-6]. We have

$$\Delta h_{av} = n_k \cdot \Delta h;\ B_{av} = n_b \cdot b;\ l_d = \sqrt{R \cdot \Delta h_{av}}, \quad (6)$$

where R – average effective roll radius.

Coefficient C_f is calculated from the formula

$$C_f = 0,8 + 1,6(B_{av} / l_d - 0,6)^{0,5}, \quad (7)$$

Inclination angle φ of the roll pass walls equals:

- for square and diamond

$$tg\varphi = h / b; \quad (8)$$

- for oval and circle

$$tg\varphi = 0,675 - 0,51[1 - 1,93(1 - 0,25b / h)^{2,5}]; \quad (9)$$

- for oval during bloom rolling

$$tg\varphi = \frac{h}{b}\left[\frac{1-(B/h)^n}{1-B/b}\right], \quad (10)$$

where Δh - absolute linear cobbing along the axis of the roll pass; h and b - height and width of the roll pass incision into the rollers; n_k and n_b - coefficients of proportionality (**Table 1**); R – effective roll radius; B – bloom width; n – exponent quantity.

Table 1.

B/h	n	B/h	n
≤1.5	3.0	2-2.5	2.3
1.8	2.65	>2.5	2.0

Coefficient of flow resistance of metal f_b at the contact surface in the transverse direction equals

$$f_b = C_f \cdot f, \quad (11)$$

Friction coefficient f during hot rolling is calculated by the model of papers [8, 9].

Equation (4) makes it possible to calculate the average value of spreading corresponding to the average area, displaced in the transverse direction of metal flow. Along the axis of the roll pass the value of spreading is different due to the shape of space for spreading in the roll pass. Manufacturers are most interested in this parameter during the calculation of roll passes, and this particular parameter of spreading (Δb_0) on the axis of the roll pass is used for comparison with the experimental data. In accordance with papers [4-6] the value of axial spreading in passes is determined by the expression

$$\Delta b_0 = \Delta b_{av} / n_s, \quad (12)$$

where n_s - coefficient taking into account the shape of space for spreading in the roll pass (**Table 2**).

Table 2. Values of coefficients n_k, n_b and n_s

Shape		Coefficients		
Billet	Roll pass	n_k	n_b	n_s
oval	ribbed oval (circle)	0.65	0.81	0.7
oval	square	0.62	0.81	0.5
square	oval	1.04-1.25	-	0.7
diamond(square)	square – diamond	0.63	0.83	0.5
circle	oval	0.71	0.86	0.7
ribbed oval	oval	0.78	0.93	0.7
hexagon	square	0.84	0.91	0.5
square	hexagon	0.98-1.08	-	0.5
rectangle	ribbed oval	1.1	0.98	0.7

Table 3. The maximum values of the lengthening coefficients during rolling in passes within diamond-square sequence when $\Delta b_0/\Delta b_\Pi = 1.0 (f = 0.3)$ (Δb_Π - space for spreading)

h, mm	b, mm	H, mm	B, mm	C_0(c), mm	q_0 mm^2	μ	D/h	b/h (H/B)
Rolling in a diamond pass								
23.8	43.7	37.5	37.5	26.5	702	1.35	10.5	1.85
48.0	85.0	73.4	73.4	52.0	2710	1.33	9.3	1.76
70.0	130	112.0	112.0	79.8	6344	1.395	8.0	1.85
113.2	183.5	170.5	170.5	121	14550	1.40	4.93	1.62
157	229	220.5	220.5	156.8	24500	1.365	3.55	1.46
Rolling in a square pass								
28.2	28.2	43.7	23.8	20	520	1.3	8.9	1.84
57.2	57.5	85.0	48.0	40.8	2040	1.25	7.7	1.76
84.6	84.6	130	70.0	60.0	4550	1.265	9.33	1.85
127	127	183.5	133.2	90.0	10400	1.283	4.42	1.62
169	169	229	157	120	18000	1.25	3.32	1.46

Taking into account the good agreement between experimental and calculated according to the formulae (4) and (12) values of spreading [4, 6], can assert that the dependence (5) gives a reliable value of the efficiency coefficient of efficiency. **Figure 1** shows that the efficiency coefficient increases with increasing effect of transverse friction forces, i.e. generalized parameter $C_f \cdot B_{av} / l_d$. This increase is most intense during the rolling of relatively narrow strips ($C_f \cdot B_{av} / l_d \prec 2$) when there is a noticeable decrease of the parameter B_{av} / l_d.

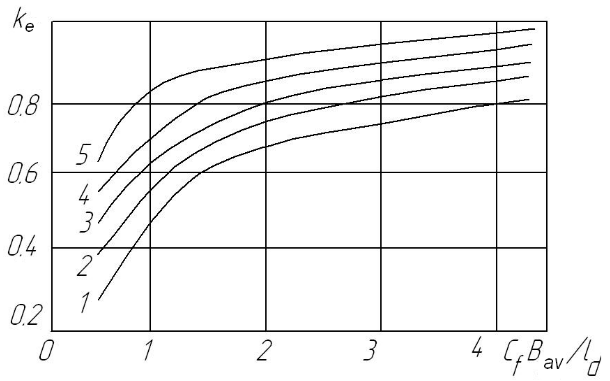

Figure 1. The effeciency coefficient of metal deformation during rolling in smooth rolls and passes at $tg\varphi / f_b$: 1 – 0; 2 – 0.5; 3 – 1.0; 4 – 2.0; 5 – 5.0

Increasing of the efficiency coefficient k_e is also contributed by an increase in inclination angle φ ща the roll pass walls at $f_b = const$ due to the large limitation of the transverse metal flow. The Figure shows that the lowest efficiency of metal deformation (with $C_f \cdot B_{av} / l_d = const$) takes place during rolling in smooth rolls (curve 1), where broadening maximum. The highest efficiency of rolling due to changes in the angle φ ($f_b = const$) is observed during metal deformation in square passes, where the angle φ = 45 ° and the maximum value of the denominator of expression (5).

The suggested model for calculating the parameters of the transverse metal flow, the reliability of which is confirmed by the experimental data, allows to determine maximum value of the lengthening coefficients for the various sequences of simple shapes passes (diamond - square, oval - square, oval - ribbed oval, oval - circle, hexagon - square (with complete filling of the pass)) (**Tables 2** and **3**). From the calculated data it follows that in each passes sequence lengthening coefficient (with complete filling of the pass) is larger in that roll pass, the width of which is larger (diamond, oval, hexagon). Thus, from Table 2 it follows that within the comparative parameters D/h (D - diameter of the rollers) lengthening coefficient in diamond passes (μ_d = 1.33-1.4) is always slightly larger than in square passes (μ_{sq} = 1.25-1.3). This ratio of the lengthening coefficients is also noted in paper [1]. Such regularity is caused by a smaller width of square passes. According to the absolute value of lengthening coefficient the considered sequences are in the following order:

- oval-square, μ = 1.4-2.4;
- hexagon-square, μ = 1.34-1.83;
- diamond-square, μ = 1.25-1.4;
- oval-ribbed oval, μ = 1.16-1.46;
- oval-circle, μ = 1.14-1.43.

The calculations show that the maximum lengthenings can be obtained during rolling blooms in the oval pass, due to a significantly higher ratio B_{av} / l_d and efficiency coefficient of rolling in the oval - ribbed oval sequence is 2-3% higher than in the oval - circle one (with all other constant parameters).

Conclusions

A new expression for definition rolling efficiency in different roll sequences passes accounting roll passes shape influence and correlation between contact resistance in cross and longitudinal direction was obtained. It was determined that the smallest coefficient of effectiveness takes place in rolling sectional bars with free spreading and it rises with increasing of roll pass walls inclination angle.

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Эффективность деформации металла в вытяжных калибрах

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Получено новое выражение для определения эффективности прокатки в калибрах различных систем, учитывающее влияние формы калибра и соотношения между контактными сопротивлениями в поперечном и продольном направлениях. Установлено, что наименьший коэффициент эффективности имеет место при сортовой прокатке со свободным уширением (гладкая бочка) и повышается с увеличением угла наклона стенок калибра.