



Study of the influence between the strength of antibending of working rolls on the widening during hot rolling of thin sheet metal

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ABSTRACT. Based on the variation principle of Jourdan was developed a mathematical model of the process of widening freely in hot rolling of thin sheet metal. The principle applies to rigid-plastic materials and for the cinematically admissible area of speeds. The developed model allows to study the distribution of the widening on the length of the deformation zone depending on the parameters of the rolling process and sheet metal. Results are obtained, characterizing the size of the widening and effectiveness of the process control on tension at the entrance and exit from the stand. The widening is dependent on the strength of anti bending.

KEYWORDS. Widening; Anti bending; Hot rolling; Thin sheet; Model

A THEORETICAL ANALYSIS OF THE PROCESS OF BROADENING

For theoretical analysis of sheet rolling, in particular, the process of broadening of the metal in the deformation zone, successfully using the energy method, based on the beginning of the possible changes of the deformed state (beginning of Lagrange). It is a kind of variation principle Jourdain, according to which the variation of the flow velocity of the metal to be in the focus of the plastic deformation. Jourdain's variation equation for the plastic deformation zone is written as follows:

$$\delta \left(\iiint_{\Omega} \Pi_v d\Omega - \iint_S \bar{\sigma}^n \bar{v} ds + \sum_{i=1}^n \iint_{S_i} \tau_s |\Delta v_i| ds \right) = 0, \quad (1)$$

where:

$\Pi_v = \int_0^H T dH$ - the speed potential;

T and H - the intensity of shear stress and shear rate;

$\bar{\sigma}^n$, \bar{v} - the total stress on the surface S with unit outward normal \bar{n} and the appropriate movement speed;



Δv_i - the velocity jump at i - the cut surface S_i ;

δ - a symbol of variation;

τ_s - the yield stress in shear.

For rigid-plastic medium (1) is rewritten as follows:

$$\delta \left(\iiint_{\Omega} \tau_s H d\Omega - \iint_S \bar{\sigma}^n \bar{v} ds + \sum_{i=1}^n \iint_{S_i} \tau_s |\Delta v_i| ds \right) = 0 \quad (2)$$

The first integral (2) is the power of internal resistance, the second - power of the external forces on the borders of the center - the forces of friction between the rolls and the strip, front and rear tension, the third - power cut.

When using the Ritz variation equation for the case of rolling Jourdain with tension in the expanded form is written as follows [1]:

$$\frac{\partial}{\partial a_j} (N_1 + N_2 + N_3 - N_4 + N_5) = 0, \quad (3)$$

where:

N_1 - the power of internal resistance;

N_2 - power sliding friction forces;

N_3 - forces cut power;

N_4 - power forward tension;

N_5 - power adjustable tension;

a_j - variable parameters.

Under the sign of differentiation is the expression for the total power rolling.

To describe the process of broadening the focus of the plastic deformation in the calculated use the circuit shown in Fig. 1. Hotbed of plastic deformation is divided into two areas - the zone and the zone timing lag. Form edge (dashed line) approximated by two straight segments - for the zone and the zone timing lag. In accordance with the scheme of the following symbols:

v_0, v_1, v_x, v_y - entrance and exit strip speed and projection velocity metal side edge on the axis x and y , respectively;

$h_0, h_i, h_1, B_0, B_i, B_1$ - the thickness and half-width of the entrance and the neutral section and the output, respectively;

ℓ, x_i - the length of the deformation zone and the zone of advance.

The equations that describe the shape of the side edges of the strip in the hearth of plastic deformation can be written as follows:

a) for the area lead $0 \leq x \leq x_i$; and b) $x_i \leq x \leq \ell$ for the zone gap

$$B_{ii}(x) = B_0 \left[1 + \beta + (\beta_t - \beta) \frac{x}{x_i} \right], \quad B_{i0}(x) = B_0 \left[1 + \frac{\beta_t}{1-t_i} - \frac{\beta_t}{1-t_i} \frac{x}{\ell} \right]$$

where:

$$\beta = \frac{\Delta B}{B_0}, \quad \beta_t = \frac{\Delta B_t}{B_0}, \quad \Delta B = B_1 - B_0, \quad \Delta B_t = B_t - B_0, \quad t_i = \frac{x_i}{\ell}.$$

From kinematic considerations we obtain the following conditions for the edge:

a) for the area lead $0 \leq x \leq x_i$, b) for the zone gap $x_i \leq x \leq \ell$

$$\frac{v_y}{v_x} \Big|_{\partial\Omega} = \frac{\Delta B - \Delta B_t}{x_i}, \quad \frac{v_y}{v_x} \Big|_{\partial\Omega} = \frac{\Delta B_t}{\ell - x_i}.$$

For every material point of the current coordinate (x, y) determined in accordance with [2-3] following law changes the flow velocity of the metal:

a) for the area lead $0 \leq x \leq x_i$; b) for the zone gap $x_i \leq x \leq \ell$



$$\frac{v_y}{v_x} = \frac{\Delta B - \Delta B_t}{x_i} \left[\frac{y}{B_{ii}(x)} \right]^p, \quad \frac{v_y}{v_x} = \frac{\Delta B_t}{\ell - x_i} \left[\frac{y}{B_{io}(x)} \right]^p, \quad (4)$$

where p - the variable parameter.

Speed v_x is determined by the law of the constancy of the second volumes:

$$v_0 h_0 B_0 = v_1 h_1 B_1 = v_x h_x B_x = v_a h_i B_i \cos \gamma, \quad (5)$$

where: V_a - the peripheral speed of the work roll; γ - neutral corner; R - radius of the work roll; $\cos \gamma = \sqrt{1 - \left(\frac{x_i}{R}\right)^2}$.

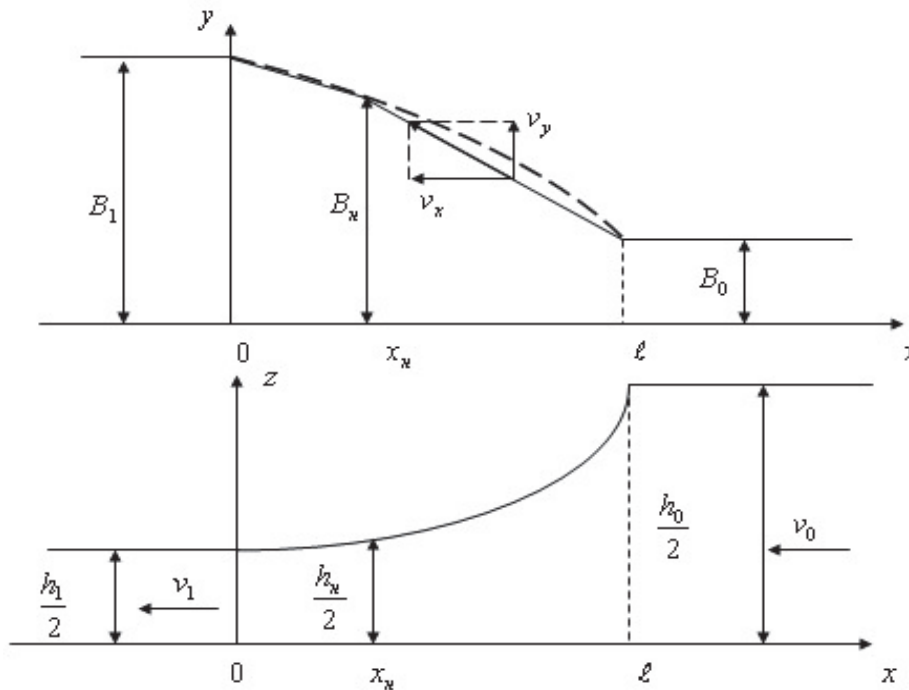


Figure 1: Design scheme.

Using well-known relations of the theory of plasticity, and acting in the same way as in [2-3], we find an expression for the intensity of the strain rate, the capacity of the internal resistance and friction, shear and tension. Compared with the model [2-3] in the developed model will be power cut in the neutral section and the power of the front and back tension. Obtain a system of three equations:

$$\begin{cases} \frac{\partial}{\partial p} (N_1 + N_2 + N_3 - N_4 + N_5) = 0 \\ \frac{\partial}{\partial (\Delta B)} (N_1 + N_2 + N_3 - N_4 + N_5) = 0, \\ \frac{\partial}{\partial (\Delta B_t)} (N_1 + N_2 + N_3 - N_4 + N_5) = 0 \end{cases} \quad (6)$$

System (6) is a mathematical model of the process of broadening the rolled strip, which can be used to study the distribution of the broadening in the deformation as a function of various parameters of rolling and strip, including the tension.



EXPERIMENTAL STUDY OF THE PROCESS OF BROADENING

To test the developed model, an experiment was conducted in a laboratory mill (diameter work rolls 120 mm). We rolled lead samples without tension, after the front end of the sample from the roll gap dwell, the rolls were bred, and the sample removed for measurement. Conditions and results of the experiment are shown in Tabs. 1 - 3.

N of exp.	h_0 , mm	$2B_0$, mm	h_1 , mm	$2B_1$, mm	Δh , mm	$2\Delta B$, mm	$l_{\text{deformation}}$, mm
1	10.1	30.1	8.15	31.4	1.95	1.3	15.0
2	10.0	15.4	7.8	16.8	2.2	1.4	16.0

Table 1: Experimental conditions

Distance from the inlet section, mm	0	3.0	6.0	9.0	12.0	15.0
$2B(x)$, mm	30.1	30.45	30.8	31.1	31.3	31.4

Table 2: Measuring the width of the sample in the deformation zone (experiment 1).

Distance from the inlet section, mm	0	4.0	7.0	10.0	13.0	16.0
$2B(x)$, mm	15.4	15.8	16.2	16.6	16.7	16.8

Table 3: Measuring width of the sample in the deformation zone (experiment 2).

The results of theoretical calculations of the experiments are presented in Tab. 4 and Figs. 2 and 3.

N of exp.	$l_{\text{deformation}}$, mm	x_t , mm	$2\Delta B_t$, mm	$2\Delta B$, mm	Exp.-theory	Relative error, %
1	15.3	5.2	1.1	1.37	-0.07	-5.4
2	16.25	4.4	1.16	1.28	0.12	8.6

Table 4: The results of theoretical calculations.

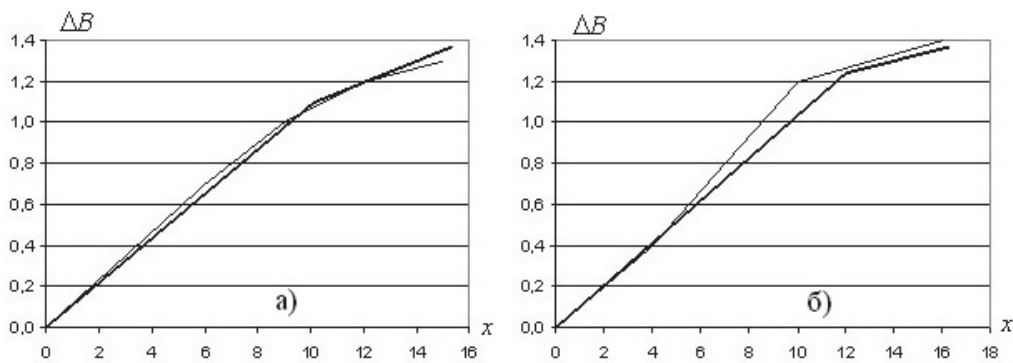


Figure 2: Comparison of the experimental and calculated data (a) Experiment 1; b) Experiment 2).

In Fig. 2 a and b shows: a thin line – experiments data, and colon - the result of a theoretical calculation. To study the effect of tension on the broadening of the two cases were calculated by application alternating front and back tension. In both cases, the specific tension was assumed to be 20% of the yield strength in tension. At this point, you must cast the remark I.Ya.Tarnovskogo [1] on a constant value by varying the tension of the full value of broadening, only

then can the correct application of the Jordan's principle. The results of calculation are shown in Figs. 3a and 3b.

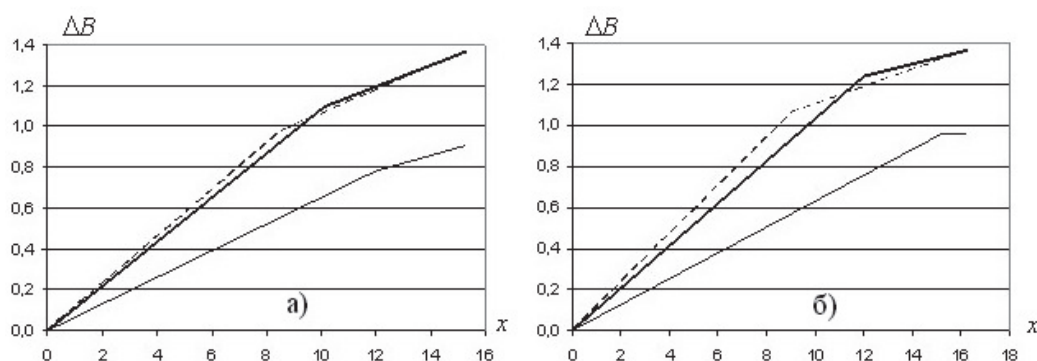


Figure 3: Effect of the anterior and posterior tension on broadening (the conditions of experiment 1, b) the conditions of experiment 2).

Thick line corresponds to the distribution of outbreak strain broadening without tension, dashed - by applying only the front tension, fine - just by applying back tension. Theoretical calculation of the behavior of the side edges of the deformation zone by applying tension corresponds to practical results.

For example, the independence of the broadening of the front tension V.N.Vydrina noted in [4] and V.P.Kalinina [5].

THE UNEVEN DISTRIBUTION OF STRESSES ON THE SPECIFIC BANDWIDTH AND BROADENING

We now turn to the Eq. (3) - it consists of different signs - power front tension, and - power adjustable tension. According to this equation, the value of broadening for the combination of thickness and tension when these power offset each other, must be equal to the broadening of the rolling without tension.

However, numerous experimental studies have shown that the value of broadening the rolling with front and rear tension less than the rolling without tension. The question arises of how these facts are consistent with the energy balance equation. It can be assumed that the application is the cause of tension in the Eq. (3) additional capacity of the forces acting on the inlet and outlet sections of the deformation zone.

To test this hypothesis using the software package NISA/DISPLAY firm EMRC (USA) finite element stress fields were built in the plate, one side of which is fixed on the movement, and the other is uniformly loaded with tensile stress. Entrenchment simulates the output section of the deformation zone. The stress field for the case of uniformly distributed applications tension within the bandwidth of the deformation zone is shown in Fig. 4.

It can be seen that the distribution of the tensile stress at the exit of the deformation zone has a pronounced unevenness, which generally can be described as a function. $\sigma_x = \varphi(y)$. This non-uniformity due to the appearance of power, called the power consumed bandwidth on the accumulation of potential energy [6,7], which is bringing a band of the deformation zone. Its value is calculated as follows:

$$N_{\dot{w}} = \tau_s v_1 h_1 \int_0^B \frac{\sigma_x^2}{2E} dy. \quad (7)$$

This power should appear in Eq. (3), together with the power of the front tension. In addition, tension band to which a tension, characterized by compressive stresses in the direction perpendicular to the rolling direction, which also influence the decrease of the broadening of the band at rolling with tension.

Similar reasoning applies to the back tension.

Changing the amount of force bending of the work rolls promotes redistribution of specific tension in width rolled strip. This changes the balance of power, and, therefore, changes the value of broadening (Fig. 5).

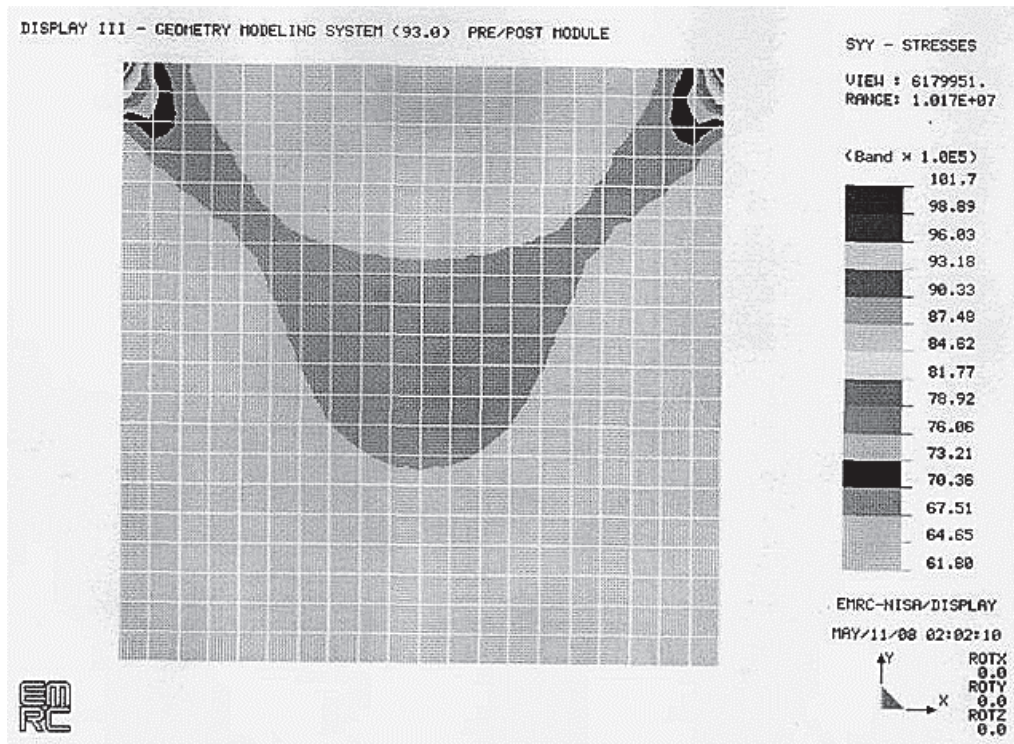


Figure 4: Distribution of tensile stress.

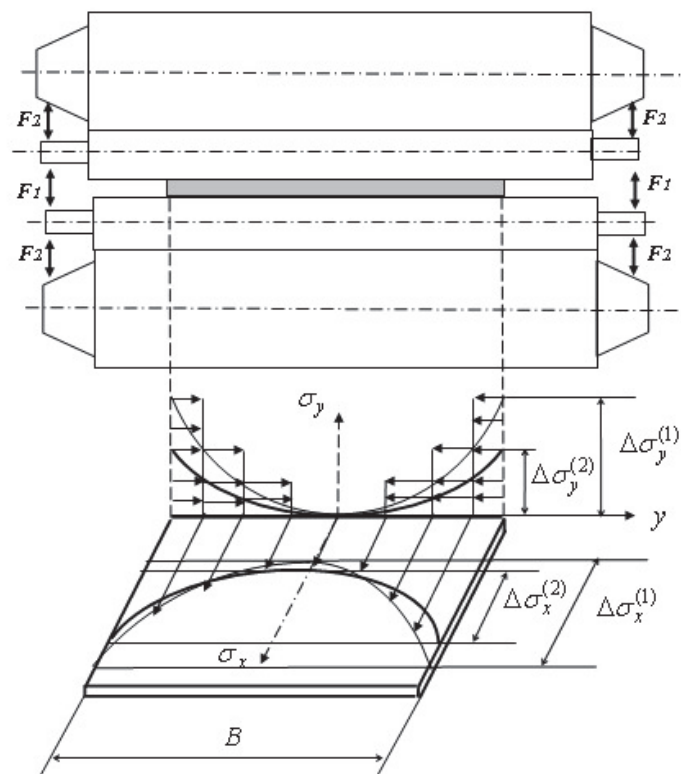


Figure 5: Impact of the work roll bending efforts on the distribution of specific tensions at the entrance and exit of deformation zone



When reducing the effort antibend F1 or increasing efforts further work roll bending F2 tensile stress in the marginal areas of the rolled strip reduced - thus broadening of the band increases. Conversely, an increase in effort antibend F1 or reduction efforts F2 additional bending tensile stress in the marginal areas increased - thus broadening of the band decreases.

CONCLUSIONS

Mathematical model of broadening rolled bands is developed and confirmed experimentally. The model allows to investigate the distribution of broadening along the source of plastic deformation, depending on the parameters of the strip rolling.

It is shown that the tension decreases with the broadening of hot rolled sheet.

It is shown that the hot-rolled sheet with a tension force of bending of the work rolls is effective.

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