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DEVELOPMENT OF A METHOD FOR CALCULATING THE DEGREE OF USE OF THE PLASTICITY RESOURCE (DUPR) WHEN ROLLING ON A NEW CONTINUOUS MILL

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Preliminary Note – Prethodno priopćenje

A new design of a continuous mill is proposed in the article. A method has been developed for calculating the degree of use of the plasticity resource when rolling thin slabs on a new continuous mill using the data obtained in the MSC Super Forge environment. To determine the stress-strain state, it used measurement data in 5 stands. When rolling in the proposed mill steel D16 there is no violation of the continuity of the strip material. This is proved by calculation in the MSC Super Forge environment using the distribution of DUPR over the cross section of strips when rolling in a mill of a new design.

Key words: rolling, steel, strip, plasticity, stress-strain

INTRODUCTION

An important factor determining the quality of thin-sheet products is the stress-strain state of the metal during rolling. Due to the complexity of its description, the corresponding calculation is usually not considered when designing rolling technology on thin-sheet mills. Therefore, the tasks related to improving the production technology of sheet steel in order to improve product quality and reduce production costs are relevant [1]. They can be solved by developing and practical development of new mills and technological methods for rolling sheet metal, evaluating the shape change and stresses in the deformation zone, etc. It has proposed a mill for continuous rolling of hot-rolled thin strips of steel and alloys. This mill for rolling strips of steel and alloys (see Figure 1) contains working stands, universal spindles, electric motor, gear stands, gearbox with bevel gears, motor coupling, main couplings, spring balancing devices of spindles; support non-drive rolls, working drive rolls, bed, base plate, anchor bolts.

At the same time, the stands with a single AC motor drive contain working and support rolls of constant diameter [2]. It should be noted that in consecutive stands, the diameter of the working rolls decreases in the direction of rolling, and the diameters of the support rolls increase. In this case, the diameters of the working and support rolls are determined by the formula, respectively:

$$D_i = \frac{\pi \cdot h_i \cdot n}{60},\ D_j = \frac{\pi \cdot h_i \cdot n}{60},$$

$$(i=1, 2,\dots, N-1, N \quad \text{by} \quad j=N, N-1,\dots 2, 1), \qquad (1)$$

where h_i – thickness of the rolled strip; n – the number of revolutions of the rolls for passage of the rolling; N – the serial number of the stand and the distance between the working rolls from one stand to another against the rolling directions increases by kh_f, h_f – final thickness of the rolled strip; k – serial number of the stand in the reverse direction of rolling. Rolling strips of steel and alloys on a continuous mill is carried out as follows. Thin slabs are fed to the furnace for heating and transferred to the first crate of the proposed mill by a roller. When moving a thin slab through a series of stands located in the direction of rolling, in which the distance between the working rolls from one stand to another against the rolling directions increases by an amount kh_f, the height is reduced and the required strip thickness is reached [3]. The standard program for determining the stress-strain state of the MSC Super Forge medium allows you to calculate the equivalent stresses, strains and temperature field, i.e. final indicators of the stress-strain state. However, this program does not allow calculating the ductility resource during rolling of hot-rolled strips, because does not provide calculated values of stress and strain tensor components.

MATERIALS AND METHODS

In connection with the above, the article based on the data obtained in the MSC Super Forge environment, proposes a method for calculating the degree of use of the plastic resource DUPR. To calculate the DUPR from the

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data obtained above, it is necessary to determine the components of the stress and strain tensor in the volume of the deformation zone and to calculate the stiffness coefficient of the stress state diagram using the obtained data. These values were calculated in the following sequence [4].

When rolling thin strips, the volume constancy conditions can be written in the following form:

$$h_{\circ} \cdot b_{\circ} \cdot l_{\circ} = y_i \cdot z_i \cdot x_i \tag{2}$$

where h_o, b_o, l_o – geometric dimensions of the deformation zone before deformation; y_i, z_i, x_i – geometric dimensions of the deformation zone after rolling in i basement.

The kinematic conditions for the constancy of second volumes can be written in the following form:

$$h_{\circ} \cdot b_{\circ} \cdot \vartheta_{\circ} = y_i \cdot z_i \cdot \vartheta_{xi} \tag{3}$$

here $\vartheta_{\circ}$ – horizontal strip speed at the entrance to the deformation zone; ϑ_{xi} – horizontal component of metal movement speed.

Solving expressions (2) and (3) together and taking into account the accepted direction of the coordinate axes, we determine the horizontal component of the speed of metal movement in the deformation zone:

$$\upsilon_{xi} = \pm\upsilon_o \frac{h_o b_o}{y_i z_i} = \pm\upsilon_o \frac{x_i}{l_o} \tag{4}$$

Introducing the coefficient of transverse deformation:

$$A = -\frac{\xi_{zi}}{\xi_{xi}} = -\frac{\ln\frac{z_i}{b}}{\ln\frac{x_i}{l_o}} \tag{5}$$

and volume constancy conditions:

$$\xi_x + \xi_y + \xi_z = 0 \tag{6}$$

where ξ_x, ξ_y, ξ_z - strain rate components, you can calculate the displacement velocity field and then the metal strain rate field using the formulas:

$$\left.\begin{aligned}
&\upsilon_{xi} = \pm\upsilon_o \frac{x_i}{l_o}; \xi_{xi} = \pm\frac{\upsilon_o}{l_o}\\
&\upsilon_{zi} = -\frac{\ln\frac{z_i}{b}}{\ln\frac{x_i}{l_o}}\frac{\upsilon_o}{l_o} z; \xi_{zi} = -\frac{\ln\frac{z_i}{b}}{\ln\frac{x_i}{l_o}}\frac{\upsilon_o}{l_o}\\
&\upsilon_{yi} = \left(\mp 1 + \frac{\ln\frac{z_i}{b}}{\ln\frac{x_i}{l_o}}\right)\frac{\upsilon_o}{l_o} y; \xi_{yi} = \left(\mp 1 + \frac{\ln\frac{z_i}{b}}{\ln\frac{x_i}{l_o}}\right)\frac{\upsilon_o}{l_o}
\end{aligned}\right\} \tag{7}$$

The components of the shear strain rates are determined by the formula:

$$\left.\xi_{xy} = \frac{1}{2}\left(\frac{\partial\upsilon_{xi}}{\partial y} + \frac{\partial\upsilon_{yi}}{\partial x}\right); \xi_{xz} = \frac{1}{2}\left(\frac{\partial\upsilon_{xi}}{\partial z} + \frac{\partial\upsilon_{zi}}{\partial x}\right); \xi_{yz} = \frac{1}{2}\left(\frac{\partial\upsilon_{zi}}{\partial y} + \frac{\partial\upsilon_{yi}}{\partial z}\right)\right\} \tag{8}$$

Substituting the field of displacement velocities from expressions (7) into equation (8), we obtain:

$$\left.\xi_{xy} = -\frac{\upsilon_o \frac{y}{l_o}\ln\frac{z}{b}}{2y\ln^2\frac{x}{l_o}};\ \xi_{yz} = \frac{\upsilon_o \frac{y}{l_o}}{2z\ln\frac{x}{l_o}};\ \xi_{zx} = \frac{\upsilon_o \frac{z}{l_o}\ln\frac{z}{b}}{2y\ln^2\frac{x}{l_o}}.\right\} \tag{9}$$

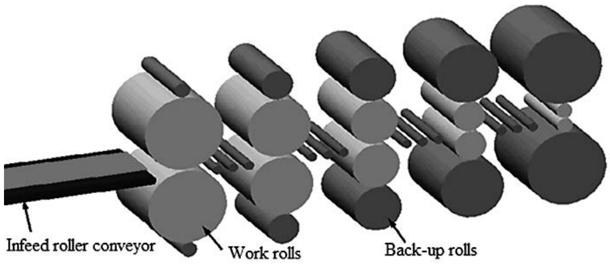


Figure 1 General view of a continuous mill stand for rolling thin strips

The intensity of the shear strain rates is determined using an equation of the form:

$$H = \frac{2}{\sqrt{6}}\sqrt{\left(\xi_{xi}-\xi_{yi}\right)^2 + \left(\xi_{xi}-\xi_{zi}\right)^2 + \left(\xi_{yi}-\xi_{zi}\right)^2 + 6\left(\xi_{xy}^2 + \xi_{xz}^2 + \xi_{yz}^2\right)} \tag{10}$$

Substituting the found values of the strain rate tensor components into equation (10), we find:

$$H = \frac{2}{\sqrt{6}}\sqrt{1 - \frac{\ln\frac{z}{b}}{\ln\frac{x}{l_o}} + \frac{\ln^2\frac{z}{b}}{\ln^2\frac{x}{l_o}} + \frac{3}{2}\left(\frac{y^2\ln^2\frac{z}{b}}{x^2\ln^4\frac{x}{H}} + \frac{z^2\ln^2\frac{z}{b}}{x^2\ln^4\frac{x}{H}} + \frac{y^2}{z^2\ln^4\frac{x}{H}}\right)} \tag{11}$$

Knowing the components of the strain rate tensor, we determine the components of the stress tensor using the following formula:

$$\sigma_{ij} - \frac{1}{3}\sigma_{ij}\delta_{ij} = \frac{2T}{H}(\xi_{ij} - \frac{1}{3}\xi_{ij}\delta_{ij}) \tag{12}$$

$$\left.\begin{aligned}
&\sigma_x - \sigma_o = \frac{2T}{H}\left(\xi_x - \xi_o\right); \quad \sigma_y - \sigma_o = \frac{2T}{H}\left(\xi_y - \xi_o\right);\\
&\sigma_z - \sigma_o = \frac{2T}{H}\left(\xi_z - \xi_o\right); \quad \tau_{xy} = \frac{2T}{H}\xi_{xy};\\
&\tau_{xz} = \frac{2T}{H}\xi_{xz}; \quad \tau_{zy} = \frac{2T}{H}\xi_{zy}.
\end{aligned}\right\} \tag{13}$$

Knowing the value of the intensity of the shear strain rate and using the hypothesis of a «single curve», while substituting the values of the shear strain rates found by equation (9) into the last three equations of system (12); we determine the shear stresses [5].

Normal voltage σ_x we find from the differential equilibrium equation of the form:

$$\frac{\partial\sigma_x}{\partial x} + \frac{\partial\tau_{xy}}{\partial y} + \frac{\partial\tau_{xz}}{\partial z} = 0 \tag{14}$$

Taking partial derivatives $\partial\tau_{xy}/\partial y$ и $\partial\tau_{xz}/\partial z$ and integrating equation (14) we determine the stress σ_x. Further, knowing the magnitude of the intensity of the shear strain rate and using the hypothesis of a «single curve» from the first equation of system (13), we find the average stress, and using the following two equations, we determine the normal stresses σ_y and σ_z.

RESULTS AND DISCUSSION

When determining the stress-strain state, it used the measurement data shown in Figure 2.

The condition for the destruction of steel and alloys during rolling in the proposed mill was estimated by the degree of use of the plasticity resource DUPR:

$$\psi = \int_0^t \frac{H(\tau)d\tau}{\Lambda_p[k_r(\tau)]} = \int_0^\varepsilon \frac{H(\varepsilon)d\tau}{\Lambda_p[k_r(\varepsilon)]} \qquad (15)$$

where Λ_p – ultimate plasticity of the metal, depending on the stress state; H – rate of shear strain; $k_r = \sigma/\grave{O}$ - the stiffness factor of stress state circuit;

$$T = \frac{1}{\sqrt{6}}\sqrt{(s_x - s_y)^2 + (s_y - s_z)^2 + (s_x - s_z)^2 + 6(t_{xy}^2 + t_{xz}^2 + t_{zy}^2)}$$

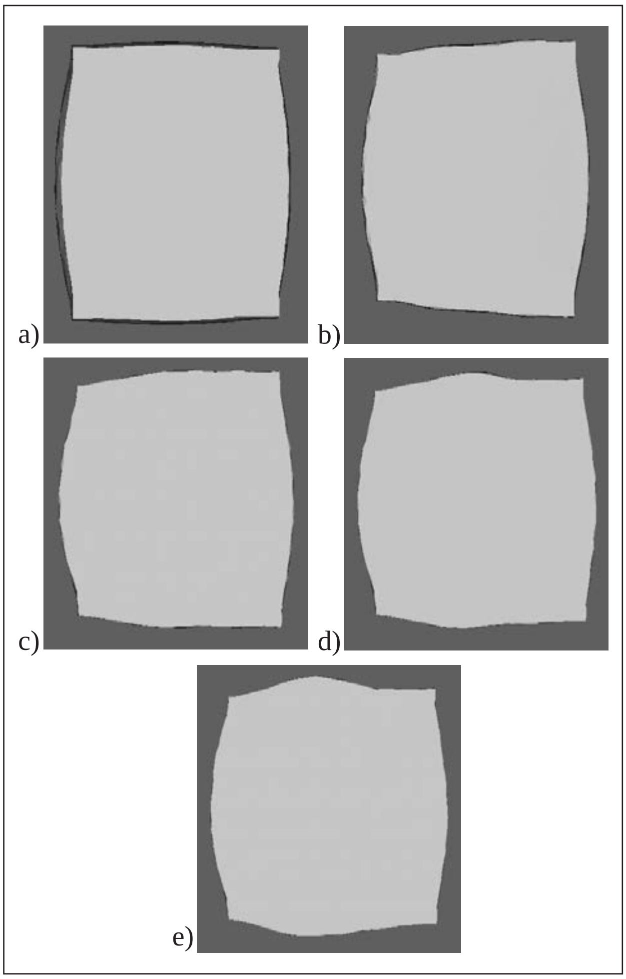
shear stress intensity; σ - average stress.

For determining Λ_p during deformation of steel D16, the regression equation obtained in the work was used:

$$\Lambda_p = 2{,}58 + 3{,}1(T_n/1000)^2 - 0{,}73(T_n/1000)\ln\xi - 0{,}64(\sigma/T) + 0{,}1(\sigma/T)\ln\xi$$

here T_H – heating temperature; ξ – strain rate.

The above method and the data obtained in the MSC Super Forge environment using the calculated DUPR showed that when rolling in the proposed mill steel of D16, there is no discontinuity of the strip material (Figures 3 and 4 l_i, h_i, b_i distance to the point of interest in length, height and width; l l_o, h_o, b_o length, height and width of the deformation zone, respectively).



a) in 1 stand; *b*) in 2 stand; *c*) in 3 stand; *d*) in 4 stand; *e*) in 5 stand

Figure 2 Geometric dimensions of the deformation zone after rolling

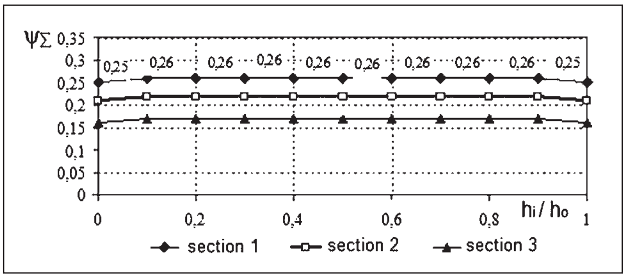


Figure 3 Distribution of DUPR over the section of strips when rolling in a new mill constructions (b_i / b_o =0,1) (section 1 - h_i / h_o = 0,9; section 2 - h_i / h_o = 0,75; section 3 - h_i / h_o = 0,5)

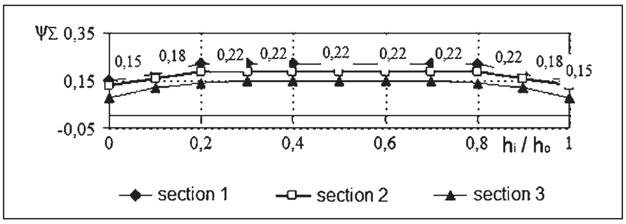


Figure 4 Distribution of DUPR over the section of strips when rolling in a mill of a new design (b_i / b_o = 0,5) (section 1 - h_i / h_o = 0,9; section 2 - h_i / h_o = 0,75; section 3 - h_i / h_o = 0,5)

CONCLUSIONS

A new design of a continuous mill is proposed;

Based on the data obtained in the MSC Super Forge environment, a methodology has been developed for calculating the degree of use of the plasticity resource when rolling thin slabs on a new continuous mill;

It has been proved by calculation that the data obtained in the MSC Super Forge environment using the calculated DUPR showed that there is no discontinuity of the strip material during rolling in the proposed steel mill.

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Note: The responsible for England language is Aigerim Nauryzbayeva, Almaty, Kazakhstan