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DETERMINING SHIFT RESISTANCE OF METAL CONSIDERING TEMPERATURE-AND-RATE CONDITIONS OF COLD ROLLING

In the paper it has been analyzed the mathematical models of double shear resistance of metal at cold thin sheet rolling. On the basis of the analysis there has been shown that it is reasonable to account the impact of temperature-rate conditions of strain in the presented models. The improved by the authors a numeric mathematical model allows specifying the calculation of doubled shear resistance of metal considering temperature and rate of cold thin sheet rolling as well as real character of distributions along the deformation zone of its dimensional parameters and indicators of external contact friction.

Key words: *cold rolling, elasticity stress, double shear resistance, temperature-rate conditions, deformation zone, mathematic simulation.*

The problem and its connection with scientific and practical tasks.

New techniques for cold rolled bars production supplying the operation of automated control systems in technological process prove the need of increasing the accuracy of applied mathematical models.

In particular, the accurate determination of the calculated values of double shear resistance of deformable metal significantly affects the prediction accuracy of power parameters of rolling [1].

Author [2] believes that the definition of computed values of yield stress σ_T and hence double shear resistance $2K$ of the metal should be implemented only as a function of compression exponent of rolled strips. In [3, 4] it is shown that neglecting the influence of temperature-rate deformation conditions leads to substantial errors in the calculation of quantities and values σ_T and $2K$. To determine the yield stress and double shear resistance for bars depending on the rate of cold rolling B. Roberts [5] developed a mathematical model that does not consider the effect of the strain temperature. More capable method of computation is proposed by A.P. Grudev and Y.B. Sigalov and is described in [6]. However, this method does not take into account the effect of the preliminary deformation of the rolled metal. Mathematical model the authors [4] does not have these shortcomings. Herewith, applied numerical approach to the computation of normal contact stresses defining the strip temperature, has a number of assumptions, the most important of which are the constancy of the friction coefficient along the length of the strained zone, the application of the friction law of Coulomb-Amonton and idealization of the actual shape of the contact surface of the work rolls. Mathematical model [7] excludes the adoption of these assumptions, and so it is interesting to update on its basis the method [4] of quantify assessment of local and integral quantities and values σ_T and $2K$.

Setting the problem.

Refinement of mathematical model for calculation of doubled shift resistance of metal considering temperature-and-rate conditions of cold rolling is an aim of the paper.

Presentation of the material and its results.

To determine the contact stresses they used mathematical model [7]. Deformation zone (fig. 1, a), consisting of zones of plastic forming length L_{pl} and elastic recovery length L_{el} broke into augment Δx to form a finite set of n-number i-th elementary volumes (fig. 1,b), which position of the boundary sections (section *ae* and *cd* in fig. 1, b) was defined by coordinates x_{i1} and x_{i2} Heights h_{xi1}.

For calculation of contact stress a mathematical model has been used [7]. Deformation zone (fig. 1, a), which consists of plastic forming areas L_{pl} and elastic recovery L_{el}, was broken with Δx augment into a finite set of n *i*–th elementary volumes (fig. 1, б), which location of boundary sections (sections *ae* and *cd* at fig. 1, б) has been determined by x_{i1} and x_{i2} coordinates. Heights $\mathrm{h}_{\mathrm{xi1}}$ and $\mathrm{h}_{\mathrm{xi2}}$ of these sections were calculated basing the approach of I.Ya.Shtaerman [8], and rates $\mathrm{V}_{\mathrm{xi1}}$ and $\mathrm{V}_{\mathrm{xi2}}$ (fig. 1, б) of metal particles motion were on the basis of sliding hypothesis [1]. Herewith a plastic forming area (fig. 1, a) has been divided into delay zone L_{bac} and outrunning zone, which length L_{adv} and depth h_n of a bar in neutral section they determine considering stress of back σ_o and frontal σ_1 tension, radial rate of rolls V_r, as well as rolling depth before h_o and after h_1 passing. To calculate contact shear stress τ_{xi1} and τ_{xi2} (fig. 1, б) one have used A.N. Levanov's principle, and to calculate normal contact (p_{xi1} and $\mathrm{p}_{\mathrm{xi2}}$) and normal axial ($\sigma_{xi1}$ and σ_{xi2}) stress they used principles of static-dynamic balance and elasticity.

Doubled shear resistance of metal considering temperature-rate influence the conditions of thin sheet cold rolling has been determined as follows [3,4]:

$$2K_{tuxi2} = 2K_{\varepsilon xi2} \cdot k_{txi2} \cdot k_{uxi2}, \qquad (1)$$

where $2K_{\varepsilon xi2}$ – current value of double shear metal resistance index, determined considering strengthening effect;

k_{txi2}, k_{uxi2} – current values of indexes considering impact of strain temperature and rate accordingly;

number 2 in the index of variables indicates a finite boundary section (section *ae* at fig. 1, б) of marked *i*–th elementary volume.

For analytical description of changing the values of $2K_{\varepsilon xi2}$ polynomials of the 3rd level have been used [7, 8]:

$$2K_{\varepsilon xi2} = 1{,}155\left(\sigma_{To} + a_1^*\varepsilon_{xi2} + a_2^*\varepsilon_{xi2}^2 + a_3^*\varepsilon_{xi2}^3\right), \qquad (2)$$

where σ_{To} – elasticity stress of metal in initial (annealed) state;

$\varepsilon_{xi2} = (H_0 - h_{xi2})/H_0$ – current values of total extent of metal compression (H_0 – depth of hot-rolled billet; $\mathrm{h}_{\mathrm{xi2}}$ – current value of bar depth in deformation zone);

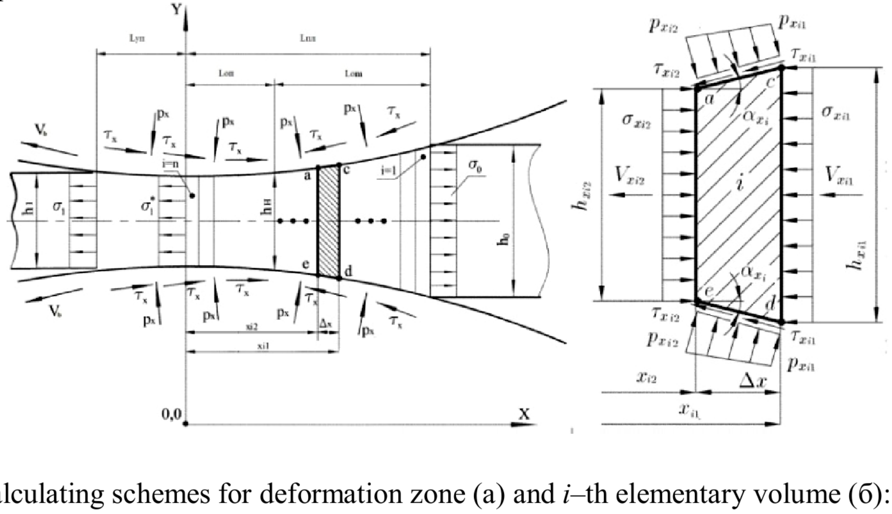

Figure 1 – Calculating schemes for deformation zone (a) and *i*–th elementary volume (б): σ_1^* – normal axial stress effective within the boundary of plastic forming and elastic recovery; α_{xi} – contact angle of *i*–th elementary volume with rols

a_1^*, a_2^*, a_3^* – indexes, which depend on chemical content of metal [8].

Values k_{txi2}, k_{uxi2} were calculated by parity of reasoning with authors [3, 4]:

$$k_{txi2} = a_0 + a_1\left(\frac{t_{xi2} - t_{cm}}{t_{пл}}\right) + a_2\left(\frac{t_{xi2} - t_{cm}}{t_{пл}}\right)^2 + a_3\left(\frac{t_{xi2} - t_{cm}}{t_{пл}}\right)^3, \quad (3)$$

$$k_{uxi2} = 1 + \frac{7682,4}{2K_{\varepsilon xi2} \cdot k_{txi2}} \times \left(\frac{u_{xi2}}{5 \cdot 10^{11} \cdot 60,842^{\ln\left(h_0/h_{xi2}\right)}}\right)^{\frac{\chi\left(t_{xi2}+273\right)}{0,14}}, \quad (4)$$

where a_0, a_1, a_2, a_3 – indexes, which depend on chemical content of metal [3];

t_{xi2} – current temperature values of a bar in deformation zone;

$t_{cT} = 20^0 C$ – metal temperature at static tests;

t_{pl} – melting temperature of metal;

$u_{xi2} = 2\Delta h V_1 h_1 \left(x_{i2} / Lnn\right) / h_{xi2}^2 L_{пл}$ – current value of strain rate (V_1 –rolling rate; $\Delta h = h_0 - h_1$ – absolute compression after skip);

χ – Boltzmann constant ($0,862 \cdot 10^{-4}$, ev/K).

Considering author's recommendations [3] to determine value t_{xi2} algorithm consequence has been used of a such type:

$$\Delta x_{xi2} = \frac{\eta_{вых} p_{пл} \lambda_{xi2}}{\gamma_М c_М}; \quad (5)$$

$$t_{xi2}^* = \frac{2\lambda h_{xi2} L_{пл}\left[1 - \left(x_{i2} / L_{пл}\right)\right]}{V_1\left(h_0 + h_{xi2}\right)}; \quad (6)$$

$$t_{xi2} = \left(t_0 + \Delta t_{xi2} - t_в\right) \times \exp\left(-\frac{4}{\gamma_м c_м\left(h_0 + h_{xi2}\right)}\sqrt{\frac{\gamma_в c_в \lambda_в t_{xi2}^*}{\pi}}\right) + t_в, \quad (7)$$

where t_{xi2} – current value along length L_{pl} (fog. 1, a) of temperature increment of a bar due to heat, which is released at plastic deformation;

p_{pl} – average pressure of metal onto rolls in the zone of plastic forming, determined considering the results of calculations of normal contact stresses p_{xi1} и p_{xi2};

η_{vyh} – index of heat release at plastic deformation equal to 0,84 – 0,94 [3];

$\lambda_{xi2} = h_0 / h_{xi2}$ – current values of compression index;

$\gamma_М, c_М$ – accordingly specific gravity and heat capacity of metal;

t_{xi2}^* – current value of contact period of particles with a roll along the area of plastic forming;

$\lambda = h_0 / h_1$ – index of bar compression during a skip;

t_0 – bar's temperature at entering into strain area;

t_v – average temperature of operating rolls;

$\gamma_в, c_в, \lambda_в$ – accordingly specific gravity, heat capacity and index of heat conductivity of operating rolls material.

As a result of numeric implementation of mathematical model (formulas (1)-(7)) have received calculated distributions along L_{pl} the values of compression level ε_{xi2}, temperature t_{xi2} and rate u_{xi2} of deformation (fig. 2), as well as values of double shear resistance of metal $2K_{\varepsilon xi2}$ and $2K_{tuxi2}$ (fig. 3). Mathematical modeling has been made for the first cage of cold thin sheet rolling of PC MISW of Ilyich.

Herewith, for initial data it was used: rolled bar grade – steel 08кп; bar depth before skip h_0 = 2 mm; bar width в = 1260 mm; compression level value during a skip ε = 0,3; rare tension stressна σ_0 = 0 MPa; front tension stress σ_1 = 100 MPa; bar's output rate from the deformation zone V_1 = 5 м/с; friction index f = 0,12.

Analysis of the results obtained during mathematical simulation has shown that temperature and strain rate variation along the deformation forming zone has got a complex character (fig. 2).

Wherein, accounting the impact of temperature-rate conditions of cold thin sheet rolling lead to redistribution of values of double shear resistance of metal (fig. 3).

In separate cases difference in values $2K_{\varepsilon xi2}$ and $2K_{tuxi2}$ can be 20% and more that has been valuable and should be considered at predicting of metal pressure onto rolls as well as power and capacity of cold rolling of thin bars.

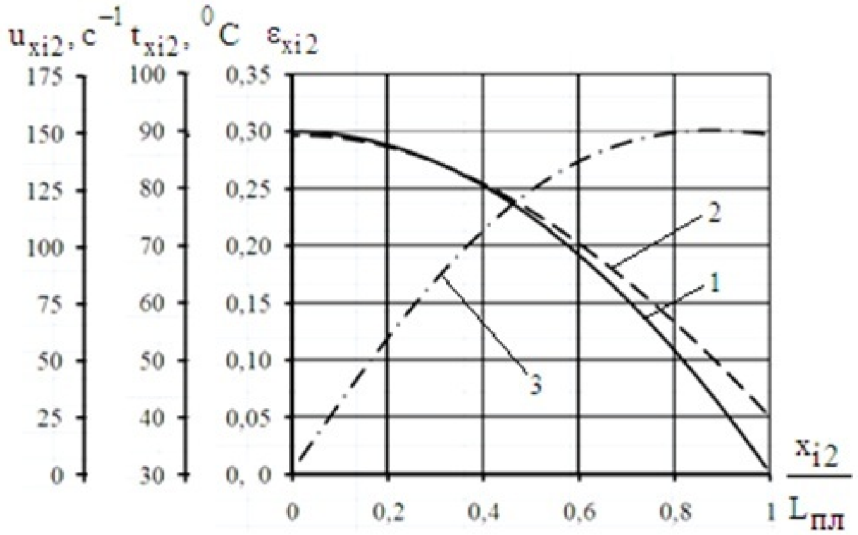

Figure 2 – Calculated distributions of values for compression level ε_{xi2} (1), strain temperature t_{xi2} (2) and rate u_{xi2} (3) along the length of plastic forming zone of deformation zone

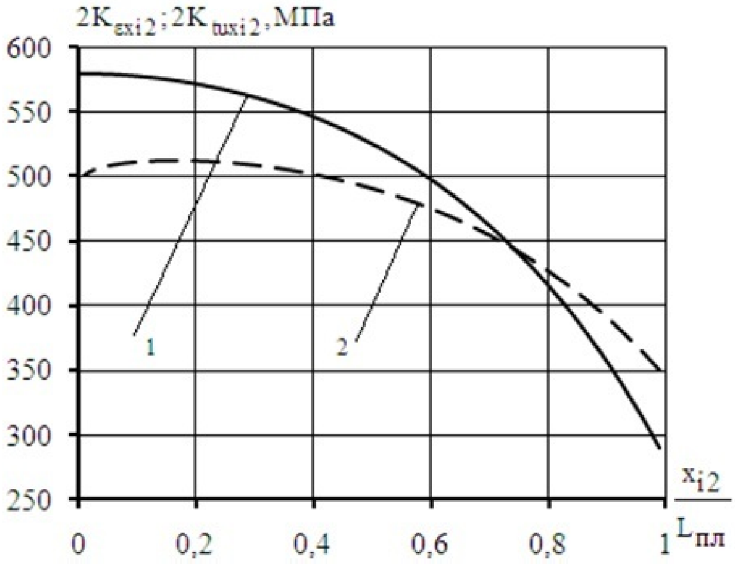

Figure 3 – Calculated distributions of values of double shear resistance of metal at cold thin sheet rolling along the length of plastic forming zone determined when considering the influence of only strengthening $2K_{\varepsilon xi2}$ (1) and temperature-rate conditions of strain $2K_{tuxi2}$ (2)

Conclusions and directions for further research.

As a result of the fulfilled researches there was refined a mathematical model for calculation of doubled shift resistance of metal considering temperature-and-rate conditions of deformation mainly meeting the real production conditions of cold rolled bars at industrial roll mills.

On the results of numeric implementation of developed model it has been found out that if impact of temperature and rate of cold thin sheet rolling onto the values σ_T and $2K$ is excluded , the assumed mistake is about 20% and more, that approves the reasonability of the problem being solved in the paper.

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ОПРЕДЕЛЕНИЕ УДВОЕННОГО СОПРОТИВЛЕНИЯ МЕТАЛЛА СДВИГУ С УЧЕТОМ ТЕМПЕРАТУРНО-СКОРОСТНЫХ УСЛОВИЙ ХОЛОДНОЙ ТОНКОЛИСТОВОЙ ПРОКАТКИ

В статье проанализированы математические модели удвоенного сопротивления металла сдвигу при холодной тонколистовой прокатке. На основе выполненного анализа показана целесообразность учета в указанных моделях влияния температурно-скоростных условий процесса деформации. Усовершенствованная авторами статьи численная математическая модель позволила уточнить расчет удвоенного сопротивления металла сдвигу с учетом температуры и скорости холодной тонколистовой прокатки, а также реального характера распределений по длине очага деформации его геометрических параметров и показателей внешнего контактного трения.

Ключевые слова: *холодная прокатка, напряжение текучести, удвоенное сопротивление сдвигу, температурно-скоростные условия, очаг деформации, математическое моделирование.*

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ВИЗНАЧЕННЯ ПОДВОЄНОГО ОПОРУ ЗРУШЕННЮ ДЕФОРМОВАНОГО МЕТАЛУ З УРАХУВАННЯМ ВПЛИВУ ТЕМПЕРАТУРНО-ШВИДКІСНИХ УМОВ ХОЛОДНОЇ ТОНКОЛИСТОВОЇ ПРОКАТКИ

У статті проаналізовані математичні моделі напруги текучості і подвоєного опору металу зрушенню при холодній тонколистовій прокатці. На основі виконаного аналізу показана доцільність обліку у вказаних моделях впливу температурно-швидкісних умов процесу деформації. Вдосконалена авторами статті чисельна математична модель дозволила уточнити розрахунок подвоєного опору металу зрушенню з врахуванням температури і швидкості холодної тонколистової прокатки, а також реального характеру розподілу по довжині осередку деформації геометричних параметрів і показників зовнішнього контактного тертя.

Ключові слова: *холодна прокатка, напруга плинності, подвоєний опір зрушенню, температурно-швидкісні умови, осередок деформації, математичне моделювання.*