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DETERMINATION OF DOUBLE SHEAR RESISTANCE OF METAL CONSIDERING THE TEMPERATURE AND RATE OF THIN SHEET COLD ROLLING

The purpose of this paper is to specify mathematic model for computation of double metal resistance to its shift considering temperature-rate conditions of cold thin sheet rolling.

Accurate determination of the computed values of double shear resistance of deformable metal significantly affects the prediction accuracy of rolling power parameters. A mathematical model in which the deformation zone consisting of zones of plastic forming and elastic recovery was discretized with augment Δx into a number of n i-th elementary volume for determination of contact stresses while sections' heights have been computed basing on I.Ya. Shteirmen's approach. Tangential contact stresseswere calculated using the A.N. Levanov's principle. Normal contact and normal axial stresses were determined according to the conditions of static-dynamic equilibrium and plasticity.

As the result of numeric implementation of specified mathematical model, computed distributions have obtained along the compression values, values of temperature and strain rate as well as double shear resistance. Mathematical simulation has executed for the first cage of thin sheet cold rolling at PC MISW of Ilyich.

Analysis of results conducted during mathematical modeling has shown that change of temperature and strain rate on the length of the plastic forming zone is complex. At the same time, consideration of the effect of temperature and strain rate conditions of cold-rolled sheet leads to a redistribution of values of double shear resistance of the metal.

Keywords: *cold rolling, stress fluctuation, double resistance changes, temperature and strain rate conditions, cell deformation, mathematical modeling.*

Introduction

Development of production technology of cold rolled strips determines the necessity to improve the accuracy of mathematical models that provide operation of automated control systems of the process. 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].

Analysis of recent publications and problem statement

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 lawof 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*.

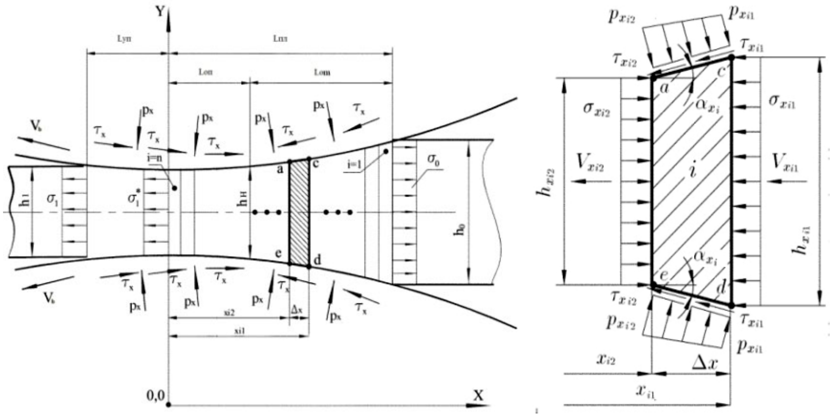
The purpose of this paper is to specify mathematic model for computation of double shear resistance of metal considering temperature-rate conditions of cold thin sheet rolling.

Mathematical model

To determine the contact stresses they used mathematical model [7]. Deformation zone (Fig. 1 a), consisting of zones of plastic forming length *Lpl* 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 $h_{x\,i\,1}$.

A mathematical model [7] has been used for calculation of contact stress. Deformation zone (fig. 1, a), which consists of plastic forming areas *Lpl* and elastic recovery L_{el}, was broken with Δx augment into a finite set of n *i–th* elementary volumes (fig. 1, b), which location of boundary sections (sections *ae* and *cd* at fig. 1, b) has been determined by x_{i1} and x_{i2} coordinates. Heights h_{xi1} and h_{xi2} of these sections were calculated basing the approach of I.Ya. Shtaerman [8], and rates V_{xi1} and V_{xi2} (fig. 1, b) of metal particles motion were on the basis of sliding hypothesis [1]. Herewith a plastic forming area (рис. 1, a) has been divided into delay zone L_{bac} and out running 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 stresses

τ_{xi1} and τ_{xi2} (fig. 1, b) one have used A.N. Levanov's principle, and to calculate normal contact (p_{xi1} and p_{xi2}) and normal axial (σ_{xi1} and σ_{xi2}) stresses they used principles of static-dynamic balance and elasticity.



a b

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

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

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

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

k_{txi2}, k_{uxi2} – are 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, b) 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]:

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

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

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

a_1^*, a_2^*, a_3^* – are indexes dependent on chemical composition of metal [8].

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

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

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

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

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

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

t_{pl} – is the melting temperature of metal;

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

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

Considering author's recommendations [3] to determine value t_{xi2} the following algorithm consequence has been used:

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

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

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

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

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

η_{vyh} – is the heat release ratio at plastic deformation (0.84 – 0.94) [3];

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

$\gamma_м, c_м$ – are relative density and heat capacity of metal, respectively;

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

$\lambda = h_0 / h_1$ – is the index of bar compression during a pass;

t_0 – is the bar temperature at the beginning of strain area;

t_v – is the average temperature of operating rolls;

$\gamma_в, c_в, \lambda_в$ – are relative density, heat capacity and index of heat conductivity of operating rolls' material, respectively.

Investigation results

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, the following initial data were used: rolled bar grade - steel 08kp; bar depth before pass h_0 = 2 mm; bar width B = 1260 mm; compression level value during a pass ε = 0.3; rare tension stress 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 variations along the deformation forming zone are of complex character (fig. 2).

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

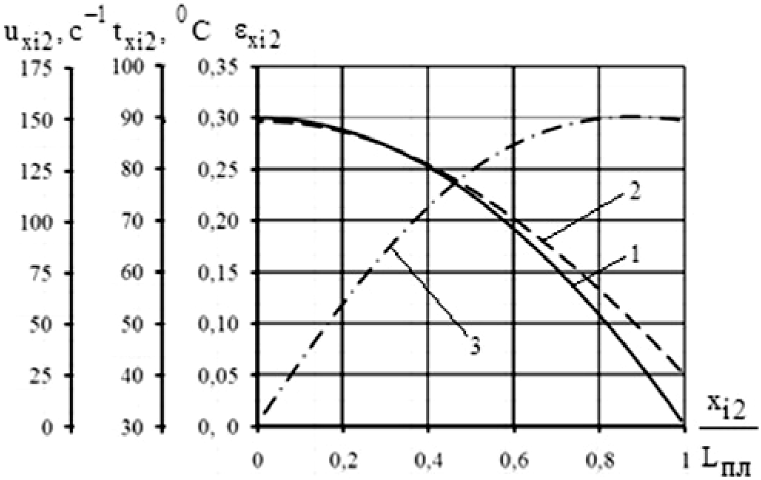


Fig. 2. Calculateddistributionsofvaluesforcompressionlevel ε_{xi2} (1), straintemperature t_{xi2} (2) andrate u_{xi2} (3) along the length of plastic forming zone of deformation zone

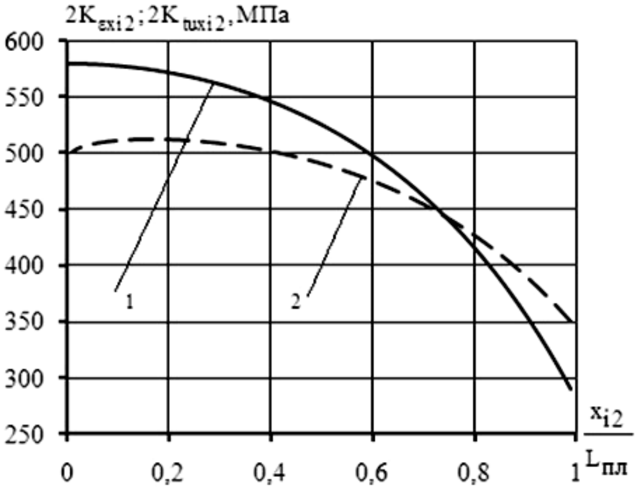


Fig. 3. Calculated distributions of values of double shear resistance of metal at cold thin sheet rolling along the length of plastic forming zone determined when considering the influence of only strengthening $2K_{\varepsilon xi2}$ (1) and temperature-rate conditions of strain $2K_{tuxi2}$ (2)

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

Conclusions

It has been specified the mathematical model for calculation of double shear resistance of metal considering the influence of temperature and strain rate conditions of strain which in greater degree corresponds to real conditions of production of cold rolled bars at industrial rolling mills. On the results of numeric implementation of developed model it has been found ou tthat if impact of temperature and rate of cold thin-sheet rolling on to the values σ_T and $2K$ are excluded, the assumed mistake is about 20% and more, that approves the reasonability of the problem being solved in this paper.

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Коробко Т.Б., Присяжний А.Г., Святий М.О., Коренко М.Г. Визначення подвоєного опору зрушенню деформованого металу з урахуванням впливу температурно-швидкісних умов холодної тонколистової прокатки.

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

Ключові слова: *холодна прокатка, напруження течії, подвоєний опір зсуву, температурно-швидкісні умови, середовище деформації, математичне моделювання.*

Коробко Т.Б., Присяжний А.Г., Святий М.О., Коренко М.Г. Определение удвоенного сопротивления металла сдвигу с учетом температуры и скорости 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.*