THE NUMERICAL PREDICTION OF FRICTION FORCES DISTRIBUTION WITHIN THE ROLL BITE WHEN HOT ROLLING STEEL

Aksenov S., Fabik R., Kliber J.
VSB - Technical University of Ostrava, Faculty of Metallurgy and Materials Engineering, Department of Materials Forming,17. listopadu 15, 708 33 Ostrava, Czech Republic,
e-mail: sergey.aksenov.st@vsb.cz

NUMERICKÝ MODEL PRO PREDIKCI ROZLOŽENÍ TŘECÍCH SIL PO DÉLCE ZÁBĚROVÉHO OBLOUKU PŘI VÁLCOVÁNÍ ZA TEPLA

Aksenov S., Fabík R., Kliber J.
VŠB – Technická univerzita Ostrava, Fakulta metalurgie a materiálového inženýrství, Katedra tváření materiálu, 17. listopadu 15, 708 33 Ostrava, Česká Republika,
e-mail: sergey.aksenov.st@vsb.cz

Abstrakt

V tomto článku je prezentována metoda vypočtu rozdělení smykového napětí v pásmu deformace na základě našíření za tepla válcovaného pásu. Za účelem stanovení závislosti součinitele tření po délce záběrového oblouku na deformačních podmínkách, bylo provedeno laboratorní válcování oceli S235J2G3 v teplotním rozmezí 900 - 1200 °C z poměrnou výškovou deformací 40% na laboratorní válcovací stolici K350. Pro stanovení rozložení součinitel tření po délce záběrového oblouku byla aplikována nepřímá metoda. Jako řídící parametr metody byla použita šířka pásu v jednotlivých příčných řezech. Okrajové a počáteční podmínky matematické modelovaní vycházely z existujících laboratorních podmínek válcování. Pro vlastní analýzu byla využita modifikovaná metoda konečných prvků v řezech. Pro výpočet distribuce třecích sil při kontaktu provalku s válci po délce záběrového oblouku byla použita inverzní metoda výpočtu. Pro inicializaci modelu byla zadána geometrie pásma deformace a vlastnosti materiálu při tváření za tepla. Konečně prvkový model umožňuje získat teplotní, deformační a napětové pole, pole rychlostí deformací, válcovací moment, válcovací sílu a povrchové napětí. Na základě znalosti povrchového smykového napětí, tlaku na válce a deformačního odporu byly stanoveny závislosti koeficientu tření na poloze vůči neutrální rovině podle Coulombova a Trescova modelu tření. Na základě těchto výsledků bylo provedeno porovnání modelů Columba a Trescy. Bylo zjištěno ze součinitel tření v obou případech není konstantní po délce pásma deformace. Nejvýznamnější rozdíl ve výsledcích získaných z obou metod je v zóně předstihu. Absolutní hodnota smykového napětí je nejnižší v neutrální rovině.

Abstract

In the paper the method of calculation of sear stresses distribution in the deformation zone by spread of stock is proposed. In order to establish the dependence of friction coefficient on deformation conditions, the S235J2G3 steel strips were rolled at temperatures 900-1200 °C with 40% reduction on K350 laboratory rolling mill. For determination of friction variation the non direct method was used. Mathematic modeling was related to existing laboratory rolling conditions. The modified slab and finite element method was employed. The mathematic simulation of the process has been used to determine the variation of friction along the rolling

contact interface. For initialization of the model the deformation zone geometrics and the hot forming properties of steel were specified. The finite element based model implements the calculation of strain, strain rate and temperature distributions, roll torques, forward slip, roll pressure and interfacial shear stress. The coefficients of friction for Coulomb and Tresca friction formulations were determined from the shear stress, the roll pressure and the yield stress distributions. The comparison of Coulomb and Tresca friction factor distributions was made. It was indicate that friction coefficient in both cases is not constant along the contact length. The differences between the Coulomb and Tresca friction factors were found more significant in the zone of slippage. The absolute value of the shear stress was found to decrease towards the neutral section.

Key words: Rolling friction, FEM, slab method, friction variation, mathematic simulation

1. Introduction

Friction is a one of the largest sources of error and uncertainty in the modeling of rolling. The problem usually reduces to knowing a friction coefficient or friction factor under true rolling conditions. Thus, typically only two friction formulations are used [1, 2].

Coulomb's friction law states that the friction force (or friction stress) is proportional to the normal stress:

$$\tau = \mu p \,. \tag{1}$$

Tesca friction may by written as follows:

$$\tau = -k \frac{\sigma_y}{\sqrt{3}} \,, \tag{2}$$

$$\tau_{\max} = \frac{\sigma_y}{\sqrt{3}} \,. \tag{3}$$

Here μ and k can be interpreted as an undetermined constants. σ_y - is a yield stress and p is a normal pressure.

Generally, the Coulomb model is supposed more precision in conditions of small pressure, where $p << \tau_{\max}$ and on the other hand in conditions where $p >> \tau_{\max}$, the using of Tresca friction formulation gives better results. Some combination of this formulations ware proposed in Levanov's and Wanheim-Bay's models [2, 3].

In the case of rolling, the deformation conditions in contact zone are various along the contact length. Measurement of the friction variation in deformation zone is a difficult task demanding special equipment. Another way is to determinate the friction distribution by indirect parameters. In this study the method of determination of friction variation along the rolling contact interface by spread of the stock is used.

2. Experimental conditions and analysis technique

2.1 Laboratory conditions

Unalloyed C Steel S235J2G3 was used for laboratory simulation. Flow stress of investigated steel is given by Andrejuk's equation:

$$\sigma_f = A\, T^{m_1}\, \varepsilon^{m_2}\, \dot{\varepsilon}^{m_3} \tag{4}$$

where A = 250 889 645 922 [MPa], m_1 = -3,122, m_2 = 0,174, m_3 = 0,135

Rolling was executed on K350 rolling mill [4]. It is a modified rolling mill with geometric similarity 1:15 to a four-high rolling mill 3.5 m at the Vítkovice plant. It is primarily used for reverse hot rolling of larger flat products. The rolling mill can be effectively and quickly converted to a two-high configuration by using the back-up rolls as working rolls.

Firstly the input samples were prepared by milling to the required shape and dimension (thickness = 9 mm, length = 90 mm, width = 9 and 18 mm). Each sample was measured and afterwards directly heated in an electric resistance furnace to the rolling temperature (900 - 1200 °C). The heated sample was immediately rolled to the half of their length, then taken out from the roll bite and cooled down. After cooling the width and thickness of rolled stick in deformation zone were carefully measured.

2.2 Mathematic model

To simulate a rolling process we used a mathematic model based on slab method [1, 3]. This implies that following hypothesis should bee accept. Lets in the Cartesian coordinate system *xyz* rolling executing in z-direction, assume that in each section of deformation zone by z-orthogonal plane the distribution of strain rate in direction of rolling is constant. This supposition let us to implement the retrieval of particle transference velocity in each section in following form:

$$\begin{Bmatrix} v_x(x,y) \\ v_y(x,y) \\ Cz \end{Bmatrix}, \tag{5}$$

where C=Const.

Consequently we able to construct the three-dimensional model of billet deflected mode by joining up the set of flat solutions in control sections.

At that the constant C defined in each section so as strength to axial deformation would be equal to the z-direction resultant of forces which effects on it:

$$\int_S \sigma_z\, ds = \int_{z_0}^{z} \int_L (p_z + \tau_z)\, dl\, dz \tag{6}$$

Where: σ_z - z-direction component of stress tensor,
S - the area of billet cross section,
L - contact boundary of section,
p_z - z-direction component of roller pressure,
τ_z - z-direction component of torsion stress.

Note that σ_z, S, L, p_z and τ_z are functions of *z*.

To estimate the strain rate in direction of rolling the equation (2) solves by iteration procedure to definite constant C. Using a reverse procedure, the torsion stress distribution $\tilde{\tau}_z$ can be determinate. Here, $\tilde{\tau}_z$ is a value averaged by width:

$$\tilde{\tau}_z = \frac{1}{|L|}\int_L (\tau_z)dl \ . \tag{7}$$

Late we will use the symbols below:

$$S_z = \int_S \sigma_z ds \ , \tag{8}$$

$$F_z = \int_{z_0}^{z}\int_L p_z dl\, dz \ , \tag{9}$$

$$T_z = \int_{z_0}^{z}\int_L (\tau_z) dl\, dz \ , \tag{10}$$

Thus the torsion stress can be defined as follows:

$$\tilde{\tau}_z = \frac{1}{|L|}\frac{\partial T_z}{\partial z} = \frac{1}{|L|}\frac{\partial (S_z - F_z)}{\partial z} \ . \tag{11}$$

Consequently to determinate function $\tilde{\tau}_z$, is necessary to know S_z and F_z distributions which can be calculated by finite element method solving of generalized plane problem in each cross section. At that the strain rate in the direction of rolling calculated separately by experimental data of spreading in deformation zone.

3. Results and discussion

The distribution of stock spread on contact length is the input parameter of the model and mast by a smooth function. Therefore we approximate the measured points by polynomial function (fig.1).

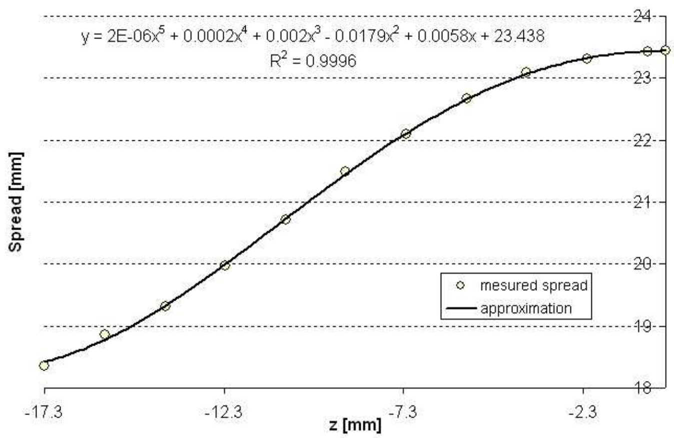

Fig.1 Spread of the stick in the roll bite.

These data were input to the finite element model. The rolling process was simulated in z-orthogonal plane by solving generalized plain task in every cross sections of deformation zone. As the deformation is symmetric about *z-x*, *z-y* plans, one quarter of the deforming workpiece was studied. In the fig. 2 are illustrated some steps of calculation.

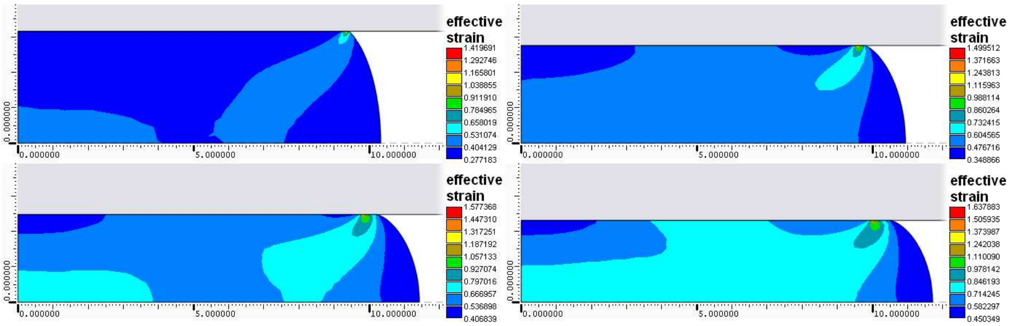

Fig.2 The effective strain distribution in different stages of deformation

In every step of calculation the value of strain rate in the direction of rolling has been varied until the calculated and given width of the billet was congruent with prescribed accuracy. The obtained dependence of strain rate on coordinate z is illustrated in fig. 3.

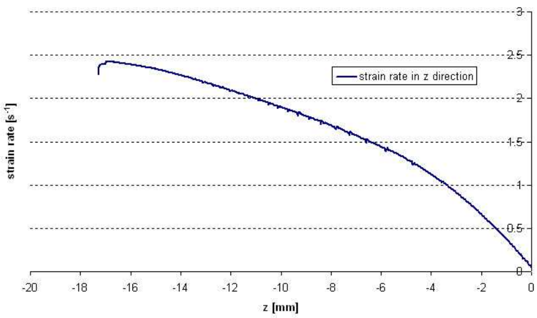

Fig.3 Distribution of strain rate in the direction of rolling within the roll bite

By distribution of deflected mode characteristics, according to the equations (7-11), we calculate the functions S_z, F_z and T_z illustrated in fig. 4.

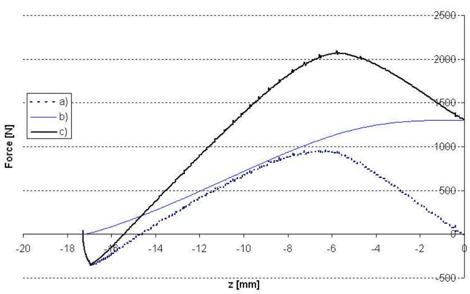

Fig.4 Variation of S_z - a), F_z -b) and T_z -c) within the roll bite

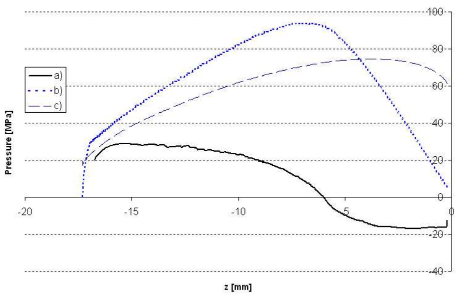

Fig.5 Variation of p - a), $\tau_{\max}$ -b) and $\tilde{\tau}_z$ -c) within the roll bite

By differentiation of T_z by coordinate z we obtain the torsion stress $\tilde{\tau}_z$ (fig. 5), which characterizes the distribution of friction forces in the contact boundary of deformation zone.

The distribution of torsion forces shown in fig. 5 is not uniform. The value of $\tilde{\tau}_z$ changes its sign by transfer from lag zone to the zone of slippage on the delivery side. At that the torsion forces decrease towards the neutral section what can be effect of decreasing of slip velocity.

By the distributions of normal stress and shear stress can be calculate the friction factors for Coulomb (1) and Tresca (2) equations.

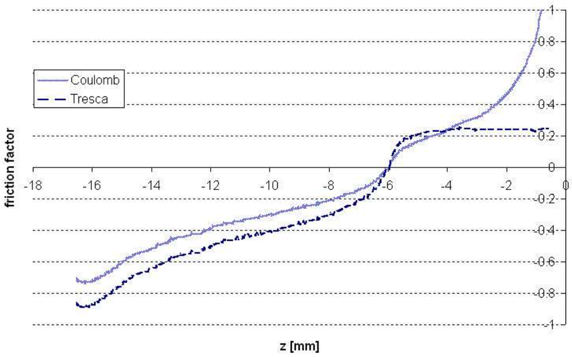

Fig.6 Coulomb and Tresca friction factors depending on z coordinate

The comparison of factors μ and k is illustrated in fig. 6. It's obvious that these coefficients are not constant in different sections of deformation zone and decreasing by coming near the neutral section.

4. Conclusions

On basis of measured spreading in deformation zone by computer simulation have been calculate deformation and force characteristics of rolling. The method of calculation of torsion stresses distribution in the deformation zone by such characteristics, have been proposed.

The obtained results indicate the nonuniform behavior of tensile stress distribution by the length of deformation zone. The tensile stress in general deceases towards the neutral section.

The Coulomb and Tresca friction factors are not constant along the contact length and their distributions have a similar character in the lag zone. In the zone of slippage, the significant differences between μ and k have been detected.

Acknowledgements

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Literature

[1] Chumachenko E.: Matematicheskoye modelirovaniye techeniya metalla pri prokatke, MIEM. –Moskva,.2005, 147p. (In Russian)

[2] Wagoner R., Chenot J.: Metal Forming Analysis. Cambridge University Press, Syndicate of the University of Cambridge 2001, ISBN 0 521 64267 1.
[3] Kumar D., Dixit U.: A slab method study of strain hardening and friction effects in cold foil rolling process. Journal of Materials Processing Technology 171 (2006) 331-340.
[4] Rolling mill K350, [online][cit. 2007-20-05]. http://fmmi10. vsb.cz/model/english/kvarto.htm