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Modeling and analysis of the correction process of billet shape in technological project of nonsymmetrical angle rolling

A. Milenin, H. Dyja, D. Svyetlichnyy

Czestochowa University of Technology,
42-200, Al.Armii Krajowej, 19, Poland

In the article the mathematical model of the shape rolling is proposed. The problem of non-isothermal metal forming during rolling in grooved rolls has been solved by using of the finite element method. As an example, the computer modeling results of the angle 150x100 mm rolling process are discussed. Influence of initial billet shape on the rolling process was modeled.

1. INTRODUCTION

Optimization of metal forming during rolling in the grooves of complex shape by mathematical model requires three-dimensional solution of transient non-isothermal task of plasticity in complex spatial configuration and transaction.

The most simulations, which study three-dimensional state of strain during rolling process, using the finite-element method consider passes separately [1-2].

Besides, in these papers the rolling of simple shape is described. They also do not solve the problem of optimization of forming technology. Mainly it is connected with the following problems:

a) Complexity of automation in preparing data and making calculations. It makes multi-calculations difficult.
b) Long time of modeling.
c) Difficulties caused by complexity of rheological alloy properties, which is studied.

Authors fulfill practical optimization of billet shape by own program SortRoll [3]. In the paper an example of nonsymmetrical angle rolling of St3S steel is presented.

2. MATHEMATICAL MODEL OF METAL DEFORMATION DURING ROLLING

In the papers [3-4] Authors present mathematical model and describe development and testing of this model which solves three-dimensional problem of metal deformation during multi-pass rolling by using the finite-element method. To obtain the solution, the theory of the non-isothermal plastic flow of incompressible non-linear viscous medium need to be applied. Boundary conditions are taken into account by the method proposed in [3]. The essential idea of the method involves the using of penalty function to reckon the conditions of metal-tools interaction in complex spatial configuration. Solution should be sought from the stationary condition of the modified Markov functional:

$$J = \tfrac{1}{2}\int_V \mu\, \dot{\varepsilon}_i^{\,2} dV + \int_V \sigma\dot{\varepsilon}_0 dV + K_\tau \int_F (v_\tau)^2 dF + K_n \int_F (v_n - w_n)^2 dF \tag{1}$$

$$K_\tau^{(p)} = \frac{\tau^{(p-1)}}{v_\tau^{(p-1)}} \tag{2}$$

$$\mu^{(p)} = \frac{2\sigma_s^{\,(p-1)}}{\sqrt{3}\dot{\varepsilon}_i^{\,(p-1)}} \tag{3}$$

where: p – iteration number; v_τ – slip metal velocity over the tool, v_n – metal velocity normal to the tool surface, w_n – velocity of tool surface point normal to the tool surface, τ – friction stress (according to the law $\tau=m\sigma_s$, where m – friction factor), σ_s – yield stress, σ – mean stress, $\dot{\varepsilon}_i$ – effective strain rate, $\dot{\varepsilon}_0$ – strain rate in the triaxial compression test, K_τ – the penalty coefficient accounting the metal slip velocity over the tool (computed from (2) by the iterations), K_n – the penalty coefficient on the metal penetration into the tool, μ – effective metal viscosity computed from (3) by the method of hydrodynamic approaches, V – volume, F – contact surface.

If the penalty coefficient K_τ increases, the metal slip over the contact surface is hampered. $K_\tau = 0$ is related to frictionless case of deformation.

In the discrete formulation some integral terms in (1) should be change as following:

$$K_\tau \int_F (v_\tau)^2 dF = K_\tau \sum_{i=1}^{N_{pov}} v_\tau^2 F_i \tag{4}$$

$$K_n \int_F (v_n - w_n)^2 dF = K_n \sum_{i=1}^{N_{pov}} (v_{ni} - w_{ni})^2 F_i \tag{5}$$

where: N_{pov} – number of grid nodes in contact with the tool, F_i – metal–tool contact surface area attached to i-th node.

3. EXPERIMENTAL PLASTOMETRIC RESEARCH AND RHEOLOGICAL MODEL IDENTIFICATION

The plastometer-dilatometer, type DIL 805 A/D manufactured by BAHR Thermoanalyse GmbH Company was used to determine steel rheologycal properties of the St3S steel. The material examinations were carried out at the temperature range of 800–1100°C, and strain rate of 0.001–10 s^{-1}. The results of a plastometric tests were approximated by the following equation:

$$\sigma_s = a_1 \varepsilon^{a_2} \exp(a_3 \varepsilon) u^{a_4} \exp(a_5 t) \tag{6}$$

where: $a_1 = 11500$, $a_2 = 0.408$, $a_3 = -1.021$, $a_4 = 0.124$, $a_5 = -0.00378$.

4. SIMULATION OF THE ROLLING OF ANGLE

In this section, computations were performed by using the model developed for calculation multi-passes rolling. The data for model validation were obtained from the industrial test rolling on a D600 rolling mill, where 150x100x10 mm angle of St3S steel was rolled in 6 passes. The initial parameters are following: temperature 1100°C, rolling speed 2 m/s. As an example of optimization pass #4 of this technology was taken. The shape and dimensions of the grooves for pass #4 is presented on the Fig. 1. Here we show stages of shape adjustment for #4 pass under condition of proper filling of grooves and straight-line metal exit from the rolls. Initial shapes of billet for different cases are shown on the Fig. 2.

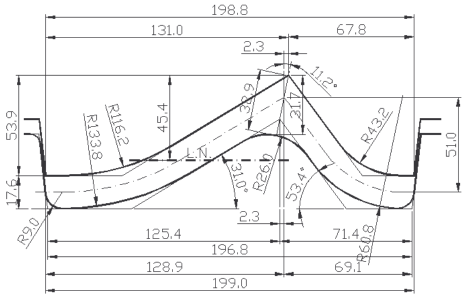
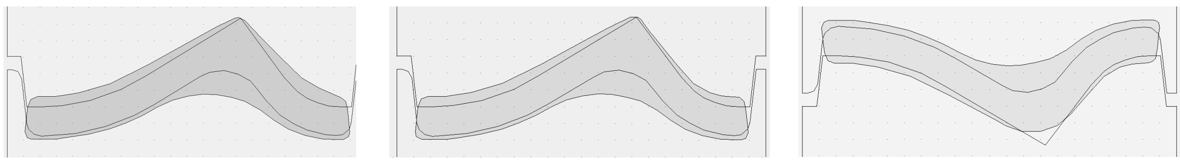
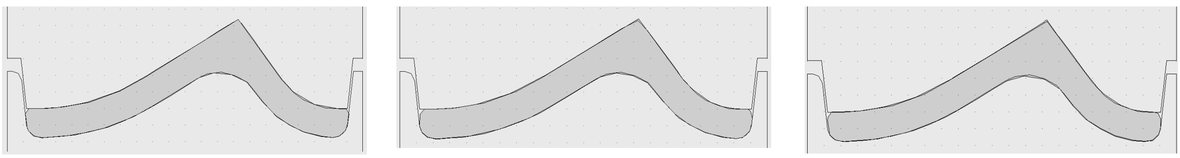


Figure 1. Blueprint of grooves used for angle billet in pass #4

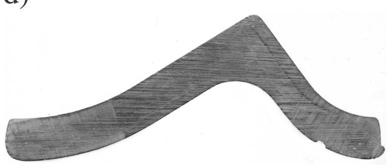


a) b) c)

Figure 2. The trail pieces of billet a) variant 1, a) variant 2, a) variant 3.



a) b) d)



f)

Figure 3. The filling of the roll grooves at the exit cross-section: a) variant 1, b) variant 2, c) variant 3, d) result of the experimental rolling according to variant 3.

Results of calculation are presented on Fig. 3. The calculations showed that the least torsion and bending are observed in the variant 3. Thus the differences of metal speed perpendicular to rolling direction for thee variants are 22.7 mm/s, 17.3 mm/s and 11.4 mm/s. While average speed in rolling direction is 620 mm/s. Mainly the speed differences drive metal upward and in the variant 3 the bending is compensated by dead weight. Therefore the variant 3 was taken as a basis for development of angle rolling schedule in six passes. The experimental cross-section is presented on Fig. 3f. Besides any metal deflection at the exit of the rolls from the straight-line is not observed both during the experimental rolling and in the modeling. The vertical speed distributions for the variant 1 and 3 are shown on the Fig. 4. One can see the vertical speed differences arise when we go from variant 1 to variant 3.

The analysis of grooves filling (Fig. 3a – Fig. 3c) shows that the grooves is fullfilled in the variant 1 only. The variant 3, which is optimal in respect to straight-line exit, exhibit underfilling about 0.5-1.0 mm (Fig. 3d). There is seen the same underfilling in the experimental cross-section (Fig. 3e). It was assumed that the underfilling is rather small and do not operate on the final dimensions of angle, that was affirm by results of experimental rolling, when the proper final dimensions were obtained.

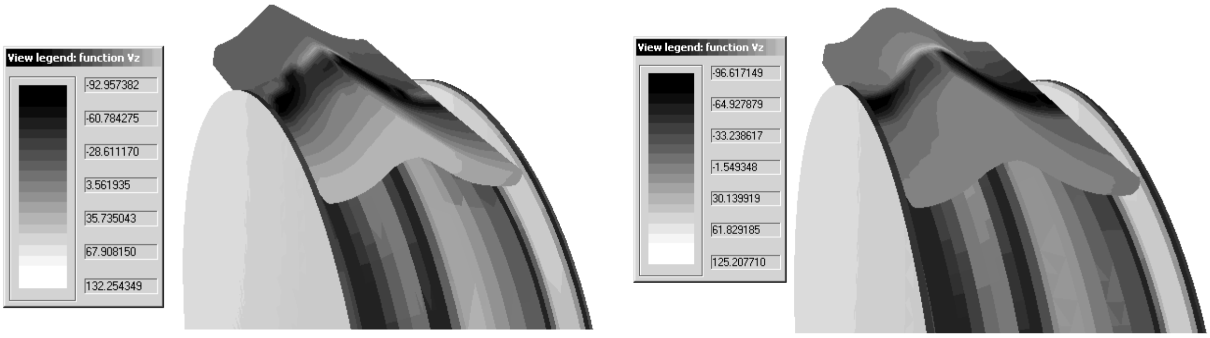


Figure 4. Vertical speed distribution v_z: a) variant 1, b) variant 3

5. CONCLUSION

The mathematical model and the program that calculate three-dimensional metal forming during the shape rolling are presented in the paper.

The example of one pass of the 150x100x10 mm angle rolling shows possibility of the shape billet optimization.

In spite of failing to satisfy all optimality condition it was chosen the variant that provide minimal both bending and torsion with the well filled grooves .

The results of the calculation is adequate to ones of the experimental rolling.

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