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NUMERICAL SIMULATION IN ROLL PASS DESIGN FOR BAR ROLLING

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The application of finite element simulation to the problem of roll pass design for round bar rolling is considered. Two roll pass sequences were developed by analytical methods and then optimized using 2.5D Finite Element Method (FEM). The first one is a classical oval-round roll pass design. The second one is a combination of flat rolls and round roll passes. Relying on the simulation data obtained by FEM, the roll gaps were adjusted to achieve the required bar shape and the uniform distribution of rolling force between the passes. Advantages and disadvantages of each roll pass design were considered.

Key words: bar rolling, rod rolling, 2.5D FEM, roll pass design, numerical simulation

INTRODUCTION

The main objective of roll pass design is to develop the sequence of individual passes which provide a product of desired size and geometry. Complicated mechanics involved in shape rolling have made the process design an art of experience [1]. That is why new computer tools and simulation methods are desired. This work is dedicated to the application of finite element simulation to the problem of roll pass design for round bar rolling built up by two symmetrical grooves. Roll pass designs were developed according to the method of Eriksson [2] based on the optimization of the rolled material cross-section at each pass. The methods of cross-section calculation for rolling in the oval-round pass sequences are considered in [3], where the results of the calculation are compared with the experimental data obtained on a laboratory rolling mill. Analytical calculation of rolling forces and moments was performed on the basis of methods proposed in [4]. Overview of the analytic equations for determination of rolling forces and moments can be found in [5].

Two pass sequences were developed and analyzed in this study. The first one is a classical oval-round roll pass design. The second one is a combination of flat rolls and round roll passes. Each pass sequence was developed in two stages. At the first stage, the sequence of roll passes and the grooves dimensions were obtained by analytical equations. At the second stage, the obtained preliminary roll pass design was optimized using the finite element software SPLEN (Rolling) based on the 2.5D method. According to the results of finite element simulation, the adjustment of the roll gaps was performed in order to prevent grooves overflow at the last pass and thus provides the required geometry of the final product.

ROLL PASS SEQUENCES

The process under consideration is rolling of a 20 mm diameter round bar from 55 mm diameter input stock. In terms of materials, this roll pass design must cover a wide range of steels, from low-carbon microalloyed steels to stainless steels. The roll pass design proposal takes into consideration the lower plasticity of certain steels.

Another special requirement was the shortest possible work length of the rolls. The standard odd number of passes was used because of the presumption that the roll pass design is a preparatory sequence of the laboratory rolling mill. The work diameter of the rolls of the two-high rolling stand was reduced to 350 mm. Two roll pass designs were proposed. The first one is a classical oval-round pass sequence with the maximum elongation coefficient of 1,55 in oval grooves and 1,35 in round grooves. The second one uses a combination of flat rolls and round roll passes. The distribution of the elongation coefficient in individual passes is similar to that in the oval-round series.

The values of spread during the rolling in individual passes were determined according the following equation [5]:

$$\Delta b = \left(0{,}58 \cdot 10^{6} h_0^2 - 0{,}00178\, h_0 + 0{,}2745\right) \Delta h, \qquad (1)$$

where h_0 is the input height and Δh is the reduction in input height after rolling.

The pass sequences obtained are presented in Figure 1. When rolling by the oval – round pass sequence, the bar is supposed to be rotated 90° after leaving the oval

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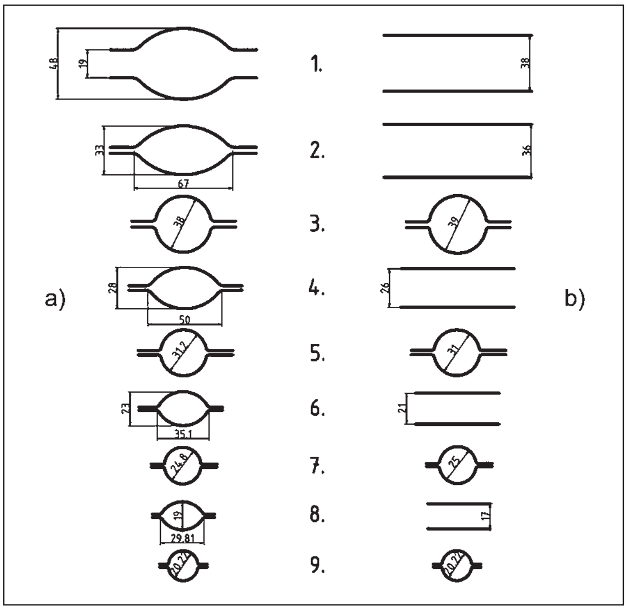

Figure 1 Schematic of roll pass design for the oval-round pass (a) and flat – round pass (b) series

pass at each operation, except the first. When rolling by the flat roll – round pass sequence, the rotation is applied every time after rolling between the flat parts of rolls.

The roll pass designs obtained by analytical methods were analyzed and optimized using computer simulation, which allows one to obtain more detailed information about the metal flow during the rolling.

2.5D FEM

Optimization tasks are usually related to a large number of simulations with different initial conditions. In this respect, high performance of the applied simulation tools is very important. Mathematical simulation based on 3D FEM is a popular and reliable way to obtain adequate models of metal flow during shape rolling. This tool is widely used for gaining understanding of metal forming during the rolling process [6-9]. The disadvantage of 3D FEM tools is that they need a significant amount of computer memory and CPU time. A number of fast simulation techniques were developed to reduce the calculation time without a significant loss of accuracy [10-13]. These techniques were successfully applied to simulations of rod and wire rolling processes [14-17].

The basis of the 2.5 D technique is the assumption that the value of z component of strain rate tensor ($\dot{\varepsilon}_z$), which characterizes the rate of elongation in the rolling direction, is constant within the cross section of a bar. The whole deformation zone is divided by cross sections into m zones with the same length: $\Delta z = l_d / m$, where l_d is the length of the deformation zone. In each zone between z_i and $z_{i+1} = z_i + \Delta z$ the field of metal flow velocity can be described as:

$$\begin{cases} v_x = v_x(x, y), \\ v_y = v_y(x, y), \\ v_z = \dot{\varepsilon}_z z, \end{cases} \tag{2}$$

The velocity field on a cross section $\{v_x, v_y\}$ is determined by finite element method (FEM) using generalized plane-strain formulation. To calculate the value of v_z, this standard FEM formulation is complemented by equilibrium equation in z direction:

$$\Omega_i = \Omega_{i-1} + R_{i-1} \tag{3}$$

$$\Omega_i = \int_{S_i} \sigma_z(x, y, z_i)\,dxdy, \tag{4}$$

$$R_i = \int_{\Gamma_i} (\sigma_{nz} + \tau_z)\,d\gamma \tag{5}$$

where Ω_i is the force acting on the section z_i, R_i - resultant force, acting on the part of the contact surface Γ_i limited by sections z_i and z_{i+1}, σ_{nz} and τ_i are z components of normal and tangential distributed forces acting on Γ_i, σ_z is a z component of stress tensor, S_i – cross section of a bar, i is the section number.

The solution is performed sequentially with i changing from 0 to m. The right part of the equation (3) is determined from the solution of the previous step. At the first step, the values of R_0 and Ω_0 are both equal to 0. The Ω_m is the force acting on the cross sections at the end of deformation zone. To satisfy the equilibrium conditions, this value must be equal to 0. Using the equations (3) and (5), the vaue of Ω_m can be found as:

$$\Omega_m = \sum_{i=0}^{m} R_i = \int_{\Gamma} (\sigma_{nz} + \tau_z)\,d\gamma \tag{6}$$

where Γ is the contact surface of the deformation zone. The value of Ω_m depends on the velocity of the bar at the input of the deformation zone which must be set before the calculation. The input velocity is determined iteratively until Ω_m is 0.

The SPLEN(Rolling) computer software was developed on the basis of the 2.5 D technique. It is able to predict the shape evolution of the rolled material, as well as distributions of strain, strain rate and temperature within the volume of the deformation zone [19]. Experimental verification shows that results obtained with this software are accurate and correspond to the experiment.

For the specification of mechanical and microstructural properties of the material during hot forming, the constitutive models and material constants described in were used.

RESULTS AND DISCUSSION

To achieve proper round shape of the bar section after the 9th pass, the roll gaps at the 8th pass were adjusted for both types of roll pass design.

The results of the simulation of rolling in flat roll – round pass series show that the distribution of rolling forces between the passes was not uniform. The rolling force in the second pass was much higher than at the rest of the passes and reached the value of 530 kN.

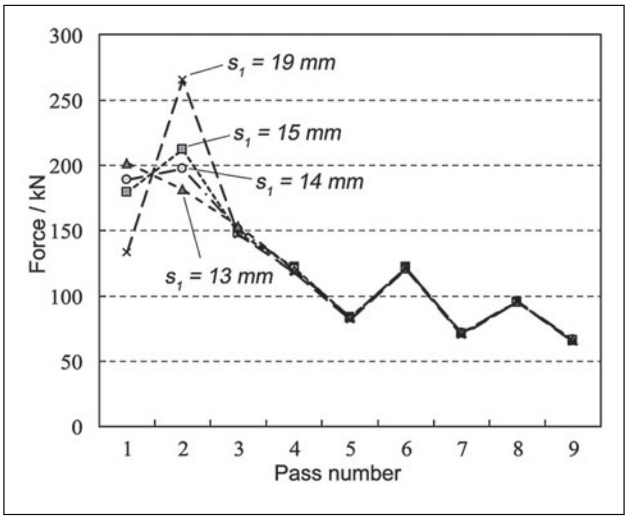

Figure 2 Distributions of rolling forces between the passes for different values of gap in the first pass

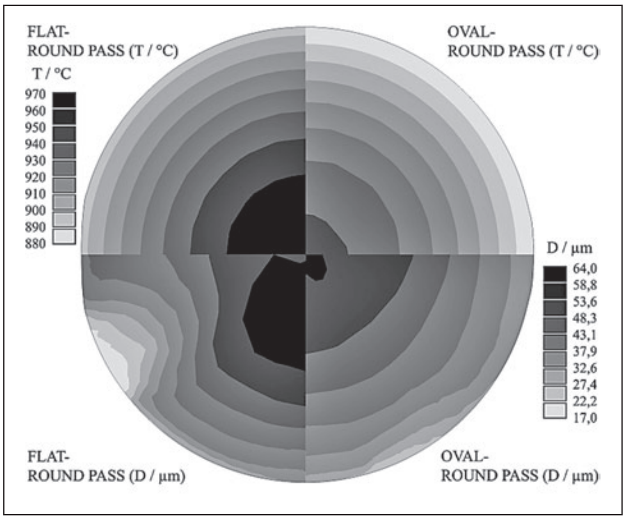

Figure 3 Distributions of final temperature and grain size obtained by simulations of rolling according to oval-round pass and flat – round pass sequences

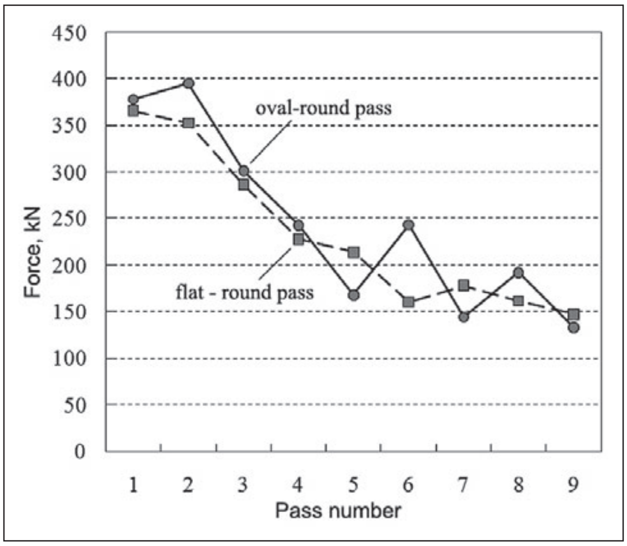

Figure 4 Distributions of rolling forces between the passes

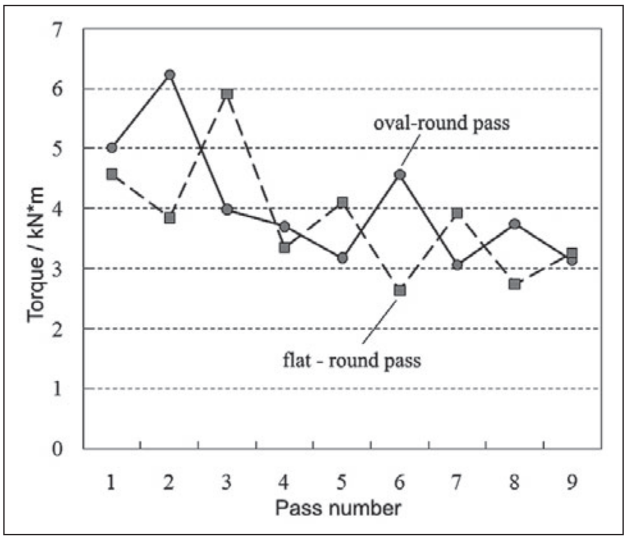

Figure 5 Distributions of rolling torques between the passes

Figure 2 shows the rolling force distributions between the passes for different values of the gap at the first pass. It can be seen that the reduction in the roll gap at the first pass to 14 mm can make the force distribution more uniform and, at the same time, decrease the maximum rolling force by more than 25 % (to the value of 194 kN).

Figure 3 shows the distributions of temperature and mean grain size within the section of the bar 30 seconds after the rolling and still air cooling. These distributions show that the final temperature of the bar rolled by the oval – round pass sequence is, on average, 20 °C lower than the one obtained after rolling by flat roll – round pass sequence. The grain size distribution is more uniform for the oval - circle roll pass design. At the same time, the grain size distributions do not differ significantly and are almost in the same range of values.

The diagrams in Figures 4 and 5 show the distributions of rolling forces and torques compared for two types of roll pass design. It can be seen that the considered roll pass designs have similar force and energy characteristics.

CONCLUSIONS

The 2.5 D technique was applied to the roll pass design problem. The simulation results were used for adjusting roll gaps to achieve the required bar shape and the uniform distribution of rolling force between the passes.

Two roll pass designs were developed and analyzed: a classical oval-round roll pass design and a combination of flat roll surfaces and round roll passes. The distributions of rolling forces and torques were obtained for both pass designs, as well as the final distributions of temperature and microstructure across the bar section.

It was shown that both considered roll pass designs are similar in terms of force and energy characteristics, as well as in terms of the final temperature and microstructure distributions. However, the advantage of the flat-round pass sequence lies in its far lower requirements for the necessary length of the working part of the roll. Five passes are carried out with the flat part of the roll, which considerably cuts down the required length of the roll body.

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Note: The responsible translator for English language is J. Drnek, Plzeň, Czech Republic