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Numerical analysis of the piercing-spreading process in skew rolling mill

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In this article has been shown numerical analysis of the rotary piercing-spreading process and the determination of the strain and stress tensor components distribution inside of the deformation zone. The rotary piercing with simultaneously expanding pipes is the main process of seamless tube manufacturing. This process is one of the most complex among the methods of shaping metals.

1. NUMERICAL MODELLING

Till now modelling piercing process about what known with accessible scientific literature [1÷5], whereas don't analysed piercing-spreading process. Therefore one should was made numerical modelling this process.

1.1 Power and rate strain

The piercing-spreading process is done on hot plastic working. Material is isotropic and inelastic.

Plastic flow metal is definite by velocity field $v_i = W_l(x,y)$; $i = r, z, \theta$, $l = 1, 2, 3$ and function $W_l(x,y)$ is presented as equation [6]:

$$W_l(x,y) = \sum_{j=1}^{n} g_j(\vartheta) \sum_{i=1}^{k} h_i(\zeta) a_{ijl} \tag{1}$$

where: $g_j(\vartheta)$, $h_i(\zeta)$ –functions of shape, a_{ijl} – variational parameters, (x,y) – local coordinates.

Functions of shape are approximated by the third degree multinomial, which guarantee continuity of strain field by using quadrangulars and four-node elements.

Power elastoplastics strain can be presented [6]:

$$\dot{W}_{pl} = \int_V \left[\sigma_p \dot{\bar{\varepsilon}} + \frac{1}{2} \Delta t \, H \left(\dot{\bar{\varepsilon}} \right)^2 \right] dV + \int_V \frac{E \, \Delta t}{6(1-2\nu)} (\dot{\varepsilon}_{rz})^2 \, dV + \int_{S_d} \tau_f \|\Delta v\| dS_d \tag{2}$$

where: σ_p- flow stress, $\dot{\bar{\varepsilon}}$ - effective strain rate, Δt- time increment, H- consolidation modulus $H = d\sigma_p / d\bar{\varepsilon}$, $d\sigma_p$- flow stress increment corresponding to the increment of the degree of strain consistent with the work-hardening curve, E- Young's modulus, ν- Poisson's values, $\dot{\varepsilon}_{rz}$ - tensor components strain rate, S_d- material-working tools contact surface, τ_f-friction force on surface S_d, $\|\Delta v\|$- velocity discontinuits on surface S_d.

Shida equation [7], defines the flow stress as a function of the temperature, effective strain and strain rate for carbon steels. The equation has the form:

$$\sigma_p = K_0 \left[1{,}3 \left(5 \varepsilon \right)^{0{,}41-0{,}07C} - 1{,}5 \varepsilon \right] \left(\frac{\dot{\varepsilon}}{10} \right)^{m_0}$$

$$K_0 = 2{,}75 \exp \left[\frac{5}{\overline{T}} - \frac{0{,}01}{C+0{,}05} \right] \tag{3}$$

$$m_0 = \left(-0{,}019C + 0{,}126 \right) \overline{T} + \left(0{,}075C - 0{,}05 \right)$$

$$\frac{T}{1000} = \overline{T} \geq 0{,}95 \frac{C+0{,}41}{C+0{,}32}$$

where: ε- effective strain, $\dot{\varepsilon}$ - effective strain rate, T- temperature in ^{o}C, C- percentage carbon.

1.2 Assumption and method of the simulation

The following assumptions have been made in analytic considerations: assuming an axial-symmetrical coordinate system and the rigid-plastic model of deformed body.

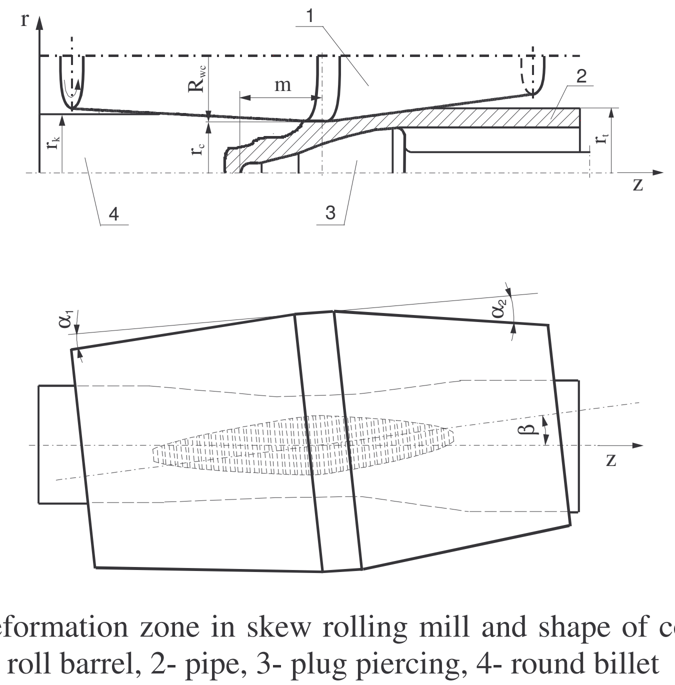

Figure 1. Schema deformation zone in skew rolling mill and shape of contact surface of the rolls and material: 1- roll barrel, 2- pipe, 3- plug piercing, 4- round billet

The shape of contact surface of the rolls and material and deformation zone in skew rolling mill are presented in Fig. 1. The stationary element of piercing-spreading process was simulated. The simulation was taken place under the following conditions: billet radius $r_k = 30$ mm; roll generatrix inclination angle input $\alpha_1 = 3^0$ and output $\alpha_2 = 7^0$ 30'; roll feed angle, $\beta = 10^0$; radius of cylindrical part of roll, $R_{wc} = 97$ mm; radius of material in the cylindrical part of roll $r_c = 26{,}4$ mm; advance plug piercing $m = 16$ mm; radius of the cylindrical part of plug piercing $r_g = 26$ mm; roll rotational speed $n = 60$ obr/min; friction factor 0,5; material steel 45; rolling temperature 1200^0C. Numerical calculations were made in computer programme TubRoll by the finite element method. This programme was made possible simulation piercing-spreading process. Results of computation were collected in text files. These files are data to later graphical work out the distribution tensor component strain and stress.

2. ANALYSIS AND EXPERIMENT RESULTS

As a result of investigated calculations, the field strain and stress were obtained. Fig. 2. shown the distribution of the tensor component strain. Maximum gradients of strain occur between the front of the head of the plug piercing and cylindrical parts of the rolls.

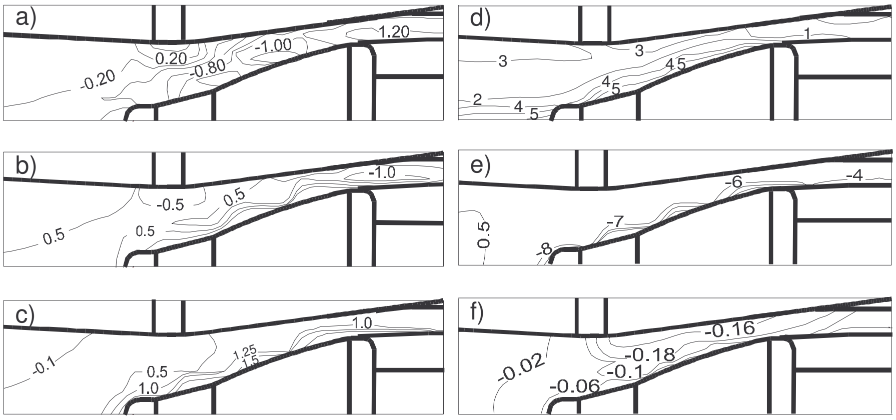

Figure 2. Distribution tensor components strain: a) ε_r; b) ε_z; c) ε_θ; d) ε_{rz}; e) $\varepsilon_{r\theta}*10^{-2}$; f) $\varepsilon_{\theta z}$

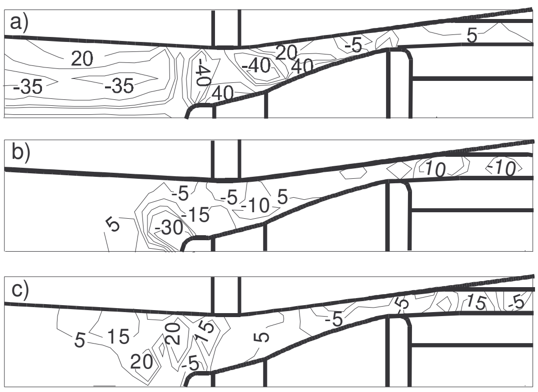

Figure 3. Distribution tensor components stress: a) σ_{rz}; b) $\sigma_{r\theta}$; c) $\sigma_{\theta z}$

Fig. 2d. shows ε_{rz} component reaches the highest values of effective strain in the whole strain area and it determines the value and distribution of the effective strain.

Fig. 3. presents distribution of the tensor components stress. As effect of intensity deformed metal between roll and plug piercing appear shearing stress. At material-plug piercing contact surface and the front of the head of the plug piercing are the highest values stress.

3. SUMMARY AND CONCLUSIONS

Simulation piercing with simultaneously expanding pipes in Diescher's mill according to the method of finite elements allows for estimating material flow in the deformation zone and distribution of strain and stress tensor components. The applied method allows to determination the dimensions of the ready pipes and adequate roll pass design and plug piercing. The analysed process is characterised by extensive strain of deformed layers of the material, especially in the field of the head of the plug piercing. The highest gradients of strain can be seen in the vicinity of the inner, formed surface, along the pipe strain field. The shear strain component ε_{rz} are caused the highest values that contribute to the effective strain and have very similar distribution. In result intensity strained metal between roll and plug piercing appear shearing stresses. On the front of the head of the plug piercing are the highest value stresses. The plug piercing is tool that forces material flow and is blamed for the size and distribution of strain and stress.

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