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Determination of Force Factors During Precipitation

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Abstract: The paper represents analytical dependences of the precipitation process on the kinematically possible flow velocities that satisfy the boundary conditions and the condition of volume constancy.

Keywords: Deformation, draft, power, intensity, surface.

INTRODUCTION

To select forging and stamping equipment in the conditions of automated production, already at the design stage of the technological process, it is necessary to know the power of the flywheel electric drive of the press and the maximum deforming force. To determine the power of a flywheel electric drive, it is necessary to calculate the work of deformation spent on deforming the workpiece during a technological operation or transition. To do this, you need to build the expected graph of the deforming force along the course of the press slider.

According to the upper bound theorem " " The power of the actual external forces at a given velocity is always less than or equal to the power of the external and internal forces at the kinematically possible ones", i.e.

$$\int_{F_v} q v_0 dF \leq \sigma_s \int_V \xi_i dV + \frac{\sigma_s}{\sqrt{3}} \int_f (v_1^* \pm v_2^*) df - \mu_s \sigma_s \int_{F_p} v^* dF \quad (1)$$

where q is the intensity of the actual external forces on the part of the workpiece surface f_v on which the flow velocities v_0 are set; 〖ξ〗_i ^* is the intensity of the kinematically possible strain rates; v_(1)^*and〖 v〗_(2) ^*are the kinematically possible flow velocities on a part of the shear velocity discontinuity surfaces; v* is the kinematically possible flow velocity on a part of the workpiece surface F_ (p,), on which the external forces F are set. In technological problems of pressure processing, such forces are the friction forces; σ_s is the yield stress (usually given according to the diagram of an ideal rigid-plastic body); μ_s is the friction factor.

Equation (1) can be solved if the kinematically possible flow velocities are known. Kinematically possible means flow velocities that satisfy the boundary conditions and the condition of constant volume.

To satisfy the condition of constant volume, it is necessary to choose one component of the flow velocity arbitrarily, satisfying only the boundary conditions, and the second one from the solution of the differential equation expressing the condition of constant volume. After selecting the kinematically possible flow rates, the kinematically possible strain rates and their intensity should be determined from the known dependences. Finally, when integrating inequality (1), difficulties arise with the integral containing the intensity of the strain rates. To overcome this difficulty, either the mean value theorem or the Bunyakovsky inequality should be used.

Using the described methodology, we provide solutions to a number of technological problems in relation to the main precipitation operations. When solving some of them, it became necessary to determine the height of the plastic deformation focus or the boundaries that determine the change in the direction of the metal flow. These parameters should be found using the minimization of the specific deforming force.

Figure 1 shows a diagram of the draft of a cylindrical billet, the problem is axisymmetric, $v_z = v_0 = 0.$

We will choose the origin in the mid-plane, which we will assume to be stationary. Given are the velocities of the particles on the end surfaces v_0 and the tangential stresses, called friction forces.

For the solution, we take a cylindrical coordinate system: X_2→O; X_3→Z. Given that the entire volume of the workpiece is in a plastic state, the expression for the upper estimate of the deforming force will take the form:

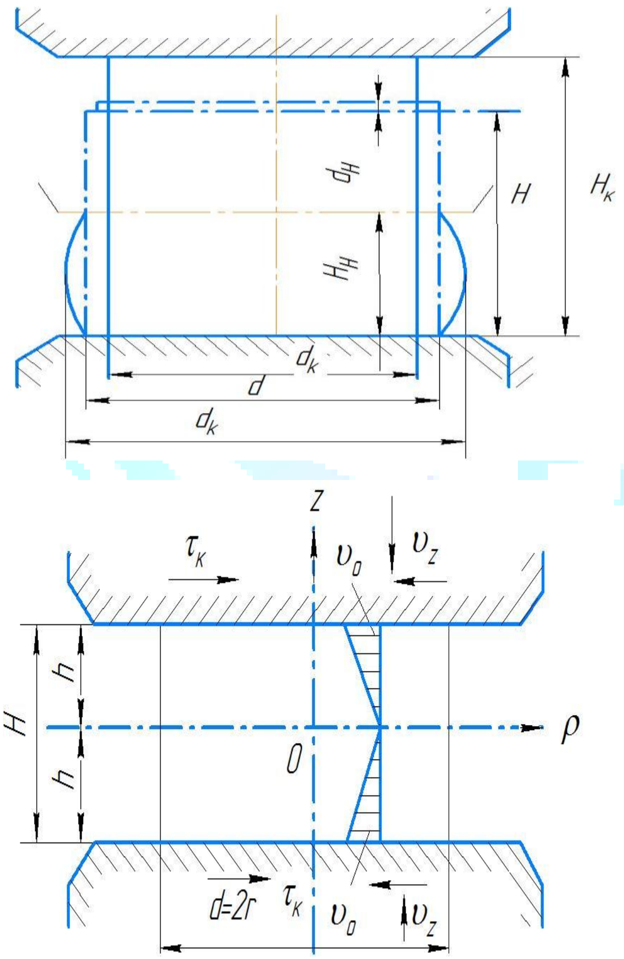

Fig. 1. Precipitation diagram.

$$\int_{F_v} (Rv_\rho + qv_z)dF \leq$$

$$q_s \int_V H^* dV - \int_{F_\rho} (Rv_\rho^* + qv_z)dF \quad (2)$$

On the end surface vz = v0, b **τ**k = R = μsσ_s are given. We transform the energy equation (2) to the form:

$$\int_{F_v} qv_0 dF \leq \tau_s \int_V H^* dV -$$

$$\int_{F_\rho} \mu_s \sigma_s v_\rho^* dF \quad (3)$$

For the solution, it is necessary to set a kinematically possible velocity field v* that satisfies the condition of constant volume and boundary conditions:

$$v_z^* = -v_0 \frac{z}{h}, \text{ тогда } \varepsilon_z^* = \frac{\partial v_z^*}{\partial z} = -v_0 \frac{1}{h}.$$

Volume constancy condition:

$$\varepsilon_\rho^* + \varepsilon_\theta^* + \varepsilon_z^* = 0.$$

Given the expression of the strain rates, we find:

$$\frac{\partial V_\rho^*}{\partial \rho} + \frac{V_\rho^*}{\rho} - v_0 \frac{1}{h} = 0$$

Converting, we get

$$\frac{1}{\rho} \frac{\partial}{\partial \rho} (\rho v_\rho^*) = v_0 \frac{1}{h}$$

As a result of integration, we have

$$\rho v_\rho^* = v_0 \frac{\rho^2}{2h} + f(z)$$

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We find an arbitrary function f(z) using the boundary conditions for

$\rho = 0, \quad v_\rho^* = 0.$

Substituting these values in the last expression, we get f(z) = 0. Then

$$v_\rho^* = v_0 \frac{\rho}{2h} \quad и \quad \varepsilon_\rho^* = \varepsilon_\theta^* = \frac{v_0}{2h} = -\frac{\varepsilon_z^*}{2}.$$

Intensity of strain rates

$$H^* = \sqrt{\frac{2}{3}} \sqrt{(\varepsilon_\rho^* - \varepsilon_\theta^*)^2 + (\varepsilon_\theta^* - \varepsilon_z^*)^2 + (\varepsilon_z^* - \varepsilon_\rho^*)^2} = \sqrt{3}\,|\varepsilon_z^*| = \sqrt{3}\,\frac{v_0}{h}$$

Substituting into the energy equation (2) we get:

$$\int_0^r q\, v_0 2\pi\rho\partial\rho \le \tau_s \int_0^k \int_0^r \sqrt{3}\,\frac{v_0}{h}\, 2\pi\rho d\rho dz + \int_0^r \mu_s \sigma_s v_0 \frac{\rho}{2h} 2\pi\rho d\rho$$

After integrating, transforming, and replacing the inequality with equality, we get:

$$\frac{q}{\sigma_s} = \frac{q}{\sqrt{3}\tau_s} = 1 + \frac{\mu_s r}{3h} \qquad (4)$$

Replacing r with d and h with H we finally have:

$$\frac{v}{\sigma_s} = 1 + \frac{\mu_s d}{3h} \qquad (5)$$

We obtained the well-known Siebel formula for determining the relative specific deforming force required for the precipitation of a cylindrical billet.

To select a forging hammer, it is necessary to find the work of deformation A. When the cylinder drains from a height of H0 to Nc (Fig. 1), the work of deformation will be equal to.

$$A = \int_{H_0}^{H_к} P dH$$

Current value of the total deforming force $P = q\sigma_s \frac{\pi d^2}{4}$

We substitute it in the integrand

$$A = -\frac{\pi}{4}\sigma_s \int_{H_0}^{H_к} \left(1 + \frac{\mu_s d}{3H}\right) d^2 dH$$

Accepting $d = d_0\sqrt{\frac{H_0}{H}}$, we substitute this expression in the integrand and, integrating, we get:

$$A = \sigma_s V\left[\ln\frac{H_0}{H_к} + \frac{2\mu_s}{9}\left(\frac{d_k}{H_k} - \frac{d_0}{H_0}\right)\right] \qquad (6)$$

where V is the volume of the workpiece to be deposited.

The second term in the square bracket defines the deformation work expended to overcome the friction forces.

CONCLUSION

The calculation of the energy-force parameters of the process of deformation of the workpiece in solving problems based on the upper bound theorem is developed.

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