Indirect extraction of bar stocks in viscous flow mode

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Abstract. The process of isothermal indirect extrusion is considered under conditions of viscoplastic metal flow, which provides the forming of high-strength nonferrous alloys. We believe that stamping is performed under conditions of strain hardening and fracture of the processed material. The deformation kinematics was established based on discontinuous path velocity fields. An expression is obtained for estimating the specific pressure during backward extrusion based on the upper boundary method. Dependencies were obtained showing the influence of the relative value of the tool stroke, reduction during extrusion, friction between the tool and the workpiece, the strain rate on the specific pressure during extrusion. The results can be used to assess the influence of technological parameters on the course of the operation.

1. Introduction
Very often in the production of products that are used in aviation technology, special non-ferrous alloys are used, which are characterized by a combination of high strength and relative lightness [1-4]. Speaking about the manufacture of these products by means of pressure treatment, it should be noted that under normal stamping conditions, their production is either laborious due to high loads and a large number of operations, or impossible due to the damage [5-8]. Therefore, it is rational to use isothermal punching, ensuring conditions of viscoplastic metal flow. All forming processes, as a rule, are unsteady and the kinematics of deformation changes in time during the forming of the workpiece [9-12].

2. Materials and methods
Stamping is performed under conditions of strain hardening and fracture of the processed material, which is associated with the short-term creep [1, 13]. In this case, the state of the material is defined as viscoplasticity in accordance with the equation [1]

\[ \sigma_i = A\varepsilon_i^{m}\xi_i^{n}, \]

where \(\sigma_i\), \(\varepsilon_i\), \(\xi_i\) is the intensity of strains, deformations and velocities, \(A\), m, n is the constants of the workpiece’s material.

Consideration of unsteadiness, hardening and creep allows calculating the optimal technological modes of pressure treatment.

The kinematics of deformation can be established on the basis of discontinuous fields of path velocities [1]. Moreover, for schemes of plane deformation the energy equation of equilibrium is valid [1]

\[ qV_0s \leq \frac{1}{\sqrt{3}}\sigma_\xi V_\xi s_\xi + \tau V_\kappa s_\kappa. \]

Here \(q\) is the pressure on the outer surface \(s\) of the workpiece (operation pressure); \(\sigma_\xi\) is the intensity of internal stresses on the surfaces \(s_p\) of the velocity gap; \(\tau\) is the friction stress on contact surfaces \(s_\kappa\); \(V_0\), \(V_\xi\), \(V_\kappa\) is the respectively are the path velocities of the deforming tool, velocity of the material at fracture surfaces and contact boundaries of friction.

Equation (2) expresses the equality of the power of external and internal forces during the deformation. Input values are determined by the kinematics of the flow of the workpiece’s material.
The calculated process diagram and velocity field are shown in fig. 1. The velocity field of the rigid blocks 0, 1, 2, separated by lines of velocity discontinuity and limited by the tool. The lengths of these lines, including the contact boundary of friction are

\[ l_{01} = \frac{h + \Delta h}{\cos \alpha}; \quad l_{12} = \frac{b}{\cos \beta}; \quad l_k = a. \]  

\[ \alpha \]

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\[
V_{m12} = \frac{(h + \Delta h) \cdot V_0}{b \cdot \sin \beta}; \quad V_{n12} = \frac{(h + \Delta h) \cdot V_0 \cos \beta}{b};
\]
\[
V_{n12}^* = l_{12} \frac{d\beta}{dt} = l_{12} \frac{d}{dt} \arctg \frac{h}{b} = \frac{V_0}{1 + \left(\frac{h}{b}\right)^2 \cos \beta};
\quad (7)
\]
\[
\varepsilon_{i01} = \frac{V_{c01}}{\sqrt{3}(V_{c01} + V_{n01})} = \frac{2}{\sqrt{3} \sin 2\alpha \left(1 - \frac{b}{h + \Delta h} \left[1 + \left(\frac{h}{b}\right)^2 \cos^2 \beta\right]^{-1}\right)}; \quad \xi_{i12} = \left(\frac{V_0}{\Delta h}\right)^n \varepsilon_{i12}^n;
\quad (8)
\]
\[
\sigma_{i12} = A \left(\frac{V_0}{\Delta h}\right)^n \varepsilon_{i12}^n.
\quad (9)
\]

The friction stress of the workpiece material at this boundary with the matrix is taken as
\[
\tau = \mu q
\quad (10)
\]
at path velocity \( V = \dot{V}_i \). Here \( q \) is the pressure of the operation; \( \mu \) is the friction coefficient.

We obtain the pressure in accordance with equation (2) by substituting the corresponding expressions
(3), (4), (6), (7), (9), (10), i.e. [1]
\[
q \leq \frac{2A}{\sqrt{3}} \left(\frac{V_0}{\Delta h}\right)^n \left(\frac{1}{\sin 2\alpha \varepsilon_{i01}^{m+n}} + \frac{1}{\sin 2\beta \varepsilon_{i12}^{m+n}}\right) \left(1 - \mu \frac{a}{h + \Delta h} \tan \alpha\right).
\quad (11)
\]
The above expression allows us to determine the specific pressure during indirect extrusion. We accepted the following values of the dimensional parameters of the process included in equation (11):
\( a = 30 \text{ mm}; b = 10 \text{ mm}, \) wall thickness \( b = 5...20\text{ mm} \). Alloys 1560 (processing temperature 450 °C) and 6Al-4V (processing temperature 930 °C) were selected as the workpiece’s material. Their mechanical characteristics are presented in the table [1].

**Table 1. Mechanical characteristics of the studied alloys**

| Material           | \( T, ^\circ\text{C} \) | \( \sigma_{e0}, \text{MPa} \) | \( A, \text{MPa} \cdot \text{sec}^n \) | \( m \) | \( n \) | \( R \) |
|--------------------|--------------------------|-----------------------------|---------------------------------|--------|--------|------|
| Aluminum alloy     | 450                      | 26.8                        | 66.8                           | 0.028  | 0.0582 | 1.06 |
| Titanium alloy     | 930                      | 38                          | 36.95                          | 0.072  | 0.0306 | 0.86 |

To assess the influence of technological parameters on the course of the operation, we obtained dependences showing the influence of the relative value of the tool stroke, reduction during extrusion, friction between the tool and the workpiece, and the strain rate on the specific pressure during extrusion.

Figure 2 shows the dependences that make it possible to establish the influence of the relative value of the tool stroke and reduction on the specific pressure of indirect extrusion.
Figure 2. The dependence of the specific pressure of the indirect extrusion on the relative value of the stroke of the tool and reduction: a) alloy 1560; b) alloy 6Al-4V

From this dependence it is seen that the specific extrusion pressure decreases with increasing stroke of the punch. Moreover, for different values of the reduction, the intensity of the pressure change is different. So for a reduction of 0.92 with an increase in stroke from 1.5 to 4, the pressure decreases by 25%. For other values of the reduction, the value of the change does not exceed 5%. This is characteristic of aluminum alloy. For a titanium alloy, for all values of reduction, the intensity of the change in force is 5%.

Figure 3 shows the dependences that allow us to establish the influence of the relative value of the tool stroke and friction on the specific indirect extrusion pressure.

Figure 3. The dependence of the specific pressure of the indirect extrusion from the relative value of the tool stroke and friction: a) alloy 1560; b) alloy 6Al-4V

From this dependence it is seen that the specific extrusion pressure decreases with an increase in the stroke of the punch and a decrease in friction. For both aluminum alloy and titanium alloy for all values of friction, the intensity of the change in force is not more than 5%.

Dependencies were obtained that made it possible to establish the influence of the value of the tool stroke and the strain rate on the specific indirect extrusion pressure (fig. 4).

Figure 4. The dependence of the specific pressure of indirect extrusion on the value of the tool stroke and the strain rate: a) alloy 1560; b) alloy 6Al-4V
From this dependence it is seen that the specific extrusion pressure decreases with an increase in the stroke of the punch and a decrease in the path velocity. For both aluminum alloy and titanium alloy for all values of friction, the intensity of the change in force is not more than 5%.

Figure 5 shows the dependences that allow us to establish the effect of reduction and friction on the specific pressure of indirect extrusion.

![Figure 5. The dependence of the specific pressure of the indirect extrusion on the reduction and friction: a) alloy 1560; b) alloy 6Al-4V](image)

From this dependence it is seen that the specific extrusion pressure varies nonlinearly with an increase in reduction. So, with the reduction increase from 0.6 to 0.8, the specific pressure decreases by 6%. Then there is its sharp growth - with the reduction increasing from 0.8 to 0.95, the specific pressure increases by 70%. This is a characteristic of the two alloys under consideration.

Figure 6 shows the dependences that make it possible to establish the effect of the strain rate on the specific pressure of indirect extrusion.

![Figure 6. The dependence of the specific pressure of indirect extrusion from the deformation rate](image)

From this dependence it is seen that the specific pressure increases with increasing speed. With an increase in the strain rate from 0.1 to 10 mm / s, the specific pressure increases by 23% for the aluminum alloy and by 15% for the titanium alloy. It can be observed that a change in velocity affects the aluminum alloy more, which is characterized by a different behavior under load.

4. Conclusion
The results of the work showed the relevance of the implementation of the viscoplasticity mode for stamping case metal products made of high-strength alloys. The graphical dependencies obtained in the course of the study can be applied to the production of thin-walled products of the "Body" type as recommendations that allow choosing rational geometric and technological parameters that provide the minimum values of technological forces.
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