Simulation of the process of extruding a bar billet into a cylindrical extrusion die with active friction

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Abstract. Backward extrusion processes are widespread when producing various axisymmetric hollow products. This process is characterized by high values of specific pressures. The meaningful task to be achieved is to reduce loads during this process implementation. The use of active friction forces to reduce loads seems to be promising. The use of a floating die with a protrusion on a cylindrical surface, which will facilitate the billet material pushing, is proposed. For theoretical justification of the process, the provision is made to use the finite-element method. The procedure was simulated for different geometric relationships of the tool, the floating extrusion die path velocities and the billet position relative to the extrusion die. The provision is made to analyze the influence of deformation parameters and velocity parameters on the change in force of the studied procedure. Based on the research findings, the conclusions on the expediency of the studied method use for its practical implementation have been made.

1. Introduction
The matter of urgency for various processes of plastic forming is to reduce loads; this is of particular importance for the process of backward extrusion [1-4]. The paper discusses the process of a steel blank backward extrusion in cold conditions [4-7]. To reduce loads, it is proposed to use a floating extrusion die [8-13]. One further distinctive feature of the floating extrusion die is a protrusion on its cylindrical part, designed to facilitate the billet material pushing. Figure 1 presents the process flow diagram.

Figure 1. Process flow diagram
2. Methods and Materials
To simulate the process, the following dimensions of the billet and tool were taken: $D_0 = 70$ mm; $D_n = 60...66$ mm; $D_M = 70...76$ mm; $h = 0...15$ mm. To implement the required scheme of deformation, the extrusion dies path velocity and the friction coefficient were varied. The billet material is steel 45. Simulation was performed via DEFORM software.

3. Results and Discussion
Figure 2 presents the “Force-path” dependence diagram for cold deformation and different friction conditions.

![Figure 2. “Force-path” dependence diagram: 1 – without active friction; 2 – with active friction and a smooth extrusion die $D_0 = 70$ mm; $D_M = 70$ mm; $D_n = 60$ mm](image)

According to this dependence diagram Curve 1 corresponds to the deformation mode without active friction, i.e. the extrusion die is fixed, wherein a typical backward extrusion process is implemented. Curve 2 corresponds to the deformation mode with active friction forces, wherein the extrusion die is movable and moves in the direction opposite to the punch movement at a velocity of $V_n = 100$ mm/s. As is seen from the diagram, the use of active friction does not give a pronounced effect in terms of reducing loads.

In connection therewith, a scheme with the extrusion die movement and the billet material pushing to it is proposed. Figure 3 presents sketch drawings, showing the pattern of metal flow during the implementation of extrusion with pushing, disclosing the essence of the proposed scheme of deformation.

Figure 4-5 present the dependences of the change in the backward extrusion force on the relative stroke of the tool for different modes of the extrusion die movement.

The data, presented in Figure 4, are valid for a smooth extrusion die and an extrusion die with a protrusion and different path velocities of the extrusion die. The data, presented in Figure 5, are valid for an extrusion die with a protrusion and different heights of the billet end above the extrusion die protrusion.
Figure 3. Scheme of metal flow during the extrusion with pushing
\( D_0 = 70 \text{ mm}; D_M = 76 \text{ mm}; D_n = 60 \text{ mm}; V_M = 170 \text{ mm/s} \)

Figure 4. “Force-path” dependence diagram: 1 – with active friction and a smooth extrusion die; 2 – with active friction, \( V_u = 120 \text{ mm/s} \); 3 – with active friction, \( V_u = 150 \text{ mm/s} \);
4 – with active friction, \( V_u = 170 \text{ mm/s} \)
\( D_0 = 70 \text{ mm}; D_M = 76 \text{ mm}; D_n = 60 \text{ mm}; h = 10 \text{ mm} \)
Figure 5. “Force-path” dependence diagram:

1 - h = 10 mm; (D₀ = 70 mm; Dₘ = 76 mm; Dₙ = 60 mm; Vₘ = 170 mm/s)
2 - h = 15 mm (D₀ = 70 mm; Dₘ = 76 mm; Dₙ = 60 mm; Vₘ = 170 mm/s)
3 - h = 15 mm (D₀ = 70 mm; Dₘ = 76 mm; Dₙ = 60 mm; Vₘ = 140 mm/s)

Figure 6-7 present the dependences of the change in the backward extrusion force on the relative stroke of the tool for different diameters of the punch.

Figure 6. “Force-path” dependence diagram:

1 - h = 15 mm (D₀ = 75 mm; Dₘ = 81 mm; Dₙ = 64 mm; Vₘ = 190 mm/s)
2 - h = 15 mm (D₀ = 75 mm; Dₘ = 81 mm; Dₙ = 64 mm; Vₘ = 260 mm/s)
Figure 7. “Force-path” dependence diagram:

1 – $h = 15$ mm ($D_0 = 75$ mm; $D_m = 81$ mm; $D_n = 66$ mm; $V_M = 190$ mm/s)

2 – $h = 15$ mm ($D_0 = 75$ mm; $D_m = 81$ mm; $D_n = 66$ mm; $V_M = 360$ mm/s)

Having analyzed Figure 4-5, it was revealed that using the scheme with the billet end pushing results in a decrease in force relative to the case with a smooth extrusion die by 17% and by 22% relative to the standard extrusion scheme. This is an unambiguous advantage of the proposed extrusion scheme. Minimum values of force can be achieved by correct combining the height $h$ and path velocity of the extrusion die (in this case, $D_0 = 70$ mm; $D_m = 76$ mm; $D_n = 60$ mm; $V_M = 170$ mm/s, $h = 15$ mm).

Having analyzed Figure 6-7, it was revealed that the use of the proposed extrusion scheme at high degrees of deformation virtually does not result in a change in force. Obviously, this is due to the fact that the wall is very thin and the scheme with pushing is no longer effective. In addition, in this case, significant tensile stresses can occur, which is undesirable.

It is also worth noting that to ensure the minimum value of the force, it is required to select the extrusion die path velocity. It should be close to the flow rate of a metal. When the extrusion die velocity is less than the flow rate of a metal, an increase in thickness occurs at the billet end and this thickening does not smooth out during the extrusion process. When the velocities of deformation exceed the flow rate of a metal, no pushing occurs due to the fact that the formed thickening is leveled at once.

Figure 8 presents the diagrams for assessing the flow rates of a metal, disclosing the essence of the flow rates of a metal to billets at different steps of deformation under the following conditions $D_0 = 75$ mm; $D_m = 81$ mm; $D_n = 66$ mm; $h = 15$ mm.
Figure 9-10 present diagrams for assessing stresses in a product under different deformation modes.

**Figure 9.** Diagrams for assessing stresses in a product under different deformation modes: a - without active friction; b - with active friction

**Figure 10.** Diagrams for assessing stresses in a product with active friction:
- a \( V_M = 140 \text{ mm/s}, \ h = 15 \text{ mm} \)
- b \( V_M = 170 \text{ mm/s}, \ h = 15 \text{ mm} \)

Having analyzed Figure 9-10, it was revealed that the use of a scheme with pushing the billet end virtually does not result in a change in the maximum tensile stress values. However, it is worth noting that in the case of pushing, in the main part of the billet, the stress state is more uniform, and the stress values are slightly less despite the similar pattern as a whole within the deformation zone.
4. Conclusion
To conclude, it is worth noting that the proposed scheme makes it possible to achieve a pronounced reduction in extrusion forces (by 20 ... 25%), but at certain values of deformation degrees, ensuring a sufficiently thick wall for pushing. This method can be used to implement the processes of backward extrusion of thick-walled volumetric billets from steel blanks.

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