Problems of Tribology, *V. 27, No 3/105-2022,55-60*

Problems of Tribology
Website: http://tribology.khnu.km.ua/index.php/ProbTrib
E-mail: tribosenator@gmail.com

DOI: https://doi.org/10.31891/2079-1372-2022-105-3-55-60

Increasing the durability of cold volume stamping equipment

Y.V. Savytskyi*, V.V. Mylko, S.S. Bys

Khmelnitskyi National University, Ukraine
**E-mail: yra.savisky@gmail.com*

Received: 15 July 2022: Revised:22 August 2022: Accept:11 September 2022

Abstract

The work examines the process of cold three-dimensional stamping, which is a very effective method of manufacturing blanks for machine parts. When using cold extrusion, high-cost stamping equipment wears out quickly and defects appear on the finished products. The development of rational technological processes of stamping helps to solve the tasks of expanding the possibilities of cold extrusion by reducing the specific force perceived by the punches, finding the optimal shape of the punch, and testing different grades of steel in order to select them according to the best operational properties. The process of radial extrusion was theoretically investigated and its mathematical model was built based on the energy method, which allows for the analysis of the force mode of extrusion and the kinematics of metal flow, to determine the relative specific force of deformation, to construct the velocity fields for different metal flow zones, and already from these data to calculate the total force deformations The resolution of the model made it possible to formulate recommendations for reducing production defects and increasing the durability of die equipment.

Key words: metal flow, deformations, extrusion, matrix, punch.

Introduction

Cold three-dimensional stamping is a highly efficient process of manufacturing parts and is widely used in the world engineering industry. Extrusion occupies a special place among volume stamping operations. In the conditions of the free economic zone with the EU, the main criteria of product competitiveness are its price and quality, which is achieved by introducing new and improving existing technologies.

Analysis of the latest research

One of the highly productive and economical processes for the production of parts is cold extrusion (CE) from alloys of non-ferrous metals and various grades of steel [1]. The economic feasibility of using cold extrusion is determined by improving the quality of parts, reducing metal consumption, reducing labor intensity, and reducing cost. The highest efficiency of cold extrusion processes is achieved in the production of axisymmetric parts and a complex shape with large differences in the intersections of cavities of different configurations [2].

Highlighting the previously unsolved part of the general problem

In fig. 1 shows a drawing of an extruded M42x2 nut blank. This nut is used to complete the high-pressure hose (Dy=25-4SH, R=320 Bar.), which ensures the operation of the power hydraulic system of grain harvesters. However, during the manufacture of this part, some problems arise, namely:

- surface defects appear (cracks, depressions, burrs, and other defects (Fig. 2);
- low stability of expensive stamping tools (matrices and punches), which reduces work productivity and increases its cost.

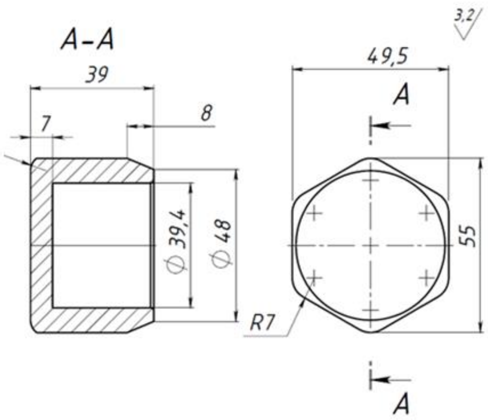


Fig. 1. Workpiece of nut S50(M42x2)

Presenting main material

The choice of one or another method in the production of products by extrusion requires the development of scientifically based technology [3], which allows predicting the mechanical characteristics of the resulting parts at the stage of designing the technological process. In addition, the development of rational technological processes contributes to the solution of the tasks of expanding the possibilities of cold extrusion by reducing the specific force perceived by punches, finding the optimal shape of the punch, and testing different grades of steel in order to select them according to the most optimal operational properties.

a) b) c)

Fig. 2. Surface defects of the nut blank obtained by cold extrusion:
a – surges, weights; b – cracks, roughness, c – longitudinal lines.

It has been theoretically proven [4] that the processes of extrusion of parts with variable wall thickness along the perimeter are characterized by a specific three-dimensional flow of metal. This flow is not axisymmetric, which has not been taken into account in theoretical solutions until now. It has been proven that extrusion takes place in two stages: the first, which occurs as a radial flow of metal, during which the festoon is formed on the upper end of the part (Fig. 3); the second is three-dimensional (vortical), i.e. all three velocity components are different from zero: vr ≠ 0; vθ ≠ 0; vz ≠ 0) (Fig. 4). The initial parameters are the dimensions of the punch r_n, the matrix A, and the workpiece $h_з$. For the first stage of deformation, we assume that radial flow takes place in zones 1, 2, zone 3 can be plastic (due to shear), and zone 4 has no deformation, therefore it is a rigid zone. Velocity fields in zones 1, 2, 3 in the cylindrical coordinate system have the following form (Fig. 3):

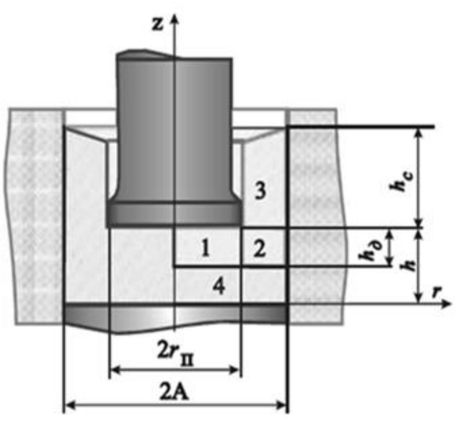


Fig. 3. Diagram of the process of radial extrusion at v_θ=0

For zones 2 and 3, the components $vr1$, $vz2$ and $vr2$ are obtained on the basis of the law of constancy of volume. Dependencies for metal flow rates, deformation rates, and intensity of deformation rates make it possible to describe the deformed state in the entire volume of the workpiece and proceed to the construction of a mathematical model of the process.

Zone 1: $h - h_\partial \le z \le h,\ 0 \le r \le r_n;\ v_{z1} = -\frac{v_n}{h} z - h_\partial - h;\ v_{r1} = \frac{v_n}{2h_\partial} \cdot r;\ v_{\theta 1} = 0;$

Zone 2: $h - h_\partial \le z \le h,\ r_n \le r \le A/\cos\theta;\ v_{z2} = -\frac{v_n}{h} - h_\partial - h \cdot f\theta;\ v_{r2} = \frac{v_n}{2h_\partial} \cdot \frac{A^2 - r^2\cos^2\theta}{r} \cdot f\theta;$

where $f\theta = \frac{r_n^2 \cos^2\theta}{A^2 - r^2\cos^2\theta};\quad v_{\theta 2} = 0;$

Zone 3: $h \le z \le h + h_c,\ r_n \le r \le A/\cos\theta;\ v_{z3} = v_n \cdot f\theta;\ v_{r3} = 0;\ v_{\theta 3} = 0;$

Zone 4: $0 \le z \le h - h_\partial,\ r_n \le r \le A/\cos\theta;\ v_{z4} = 0;\ v_{r4} = 0;\ v_{\theta 4} = 0,$

where $v_п$ – punch speed

h – is the depth of propagation of the center of plastic deformation;

h_c – the height of the part wall;

h – bottom thickness;

r, z, θ – coordinates of the cylindrical coordinate system.

To build a mathematical model of the process, we use the first basic equation of the energy method [5]:

$$F_\partial = \frac{1}{v_п}\left[\sum_{j=1}^{J}\left(\iiint \sigma_s(\varepsilon_i)\xi_i dV\right)_j + \sum_{m=1}^{M}\left(\iint \tau_k \sqrt{{v_k}^2 + {v_l}^2} dA\right)_m + \sum_{n=0}^{N}\left(\iint \tau_s \Delta v dG\right)_n\right] \tag{1}$$

where F – the variable active force in the process of deformation, H;

vп – punch speed, m/c;

$\sigma(\varepsilon_i)$ – flow stress as a function of strain intensity εi, Pa;

V – volume of the zone in the center of deformation, m^3;

κ – friction stress on the contact surfaces, Pa;

A – surface area of this element of the deformed workpiece, m^2;

v_k, v_l – speed along the generalized coordinate axes k and l, m/c;

S – shear stress on the surfaces of the speed gap, Pa;

Δv – gap of shear rates, m/c;

G – surface area of the speed gap, m^2;

J – the number of zones into which the deformation center is divided;

M – the number of contact friction surfaces;

N – the number of velocity discontinuity surfaces.

The power of the external deforming force applied to the punch:

$$N_{12} = F_\partial \cdot v_п = \pi r_П^2 \cdot p\ v_n \sigma_s, \tag{2}$$

where p – the relative specific deformation force as a function of the dimensionless depth of the distribution of the plastic deformation cell.

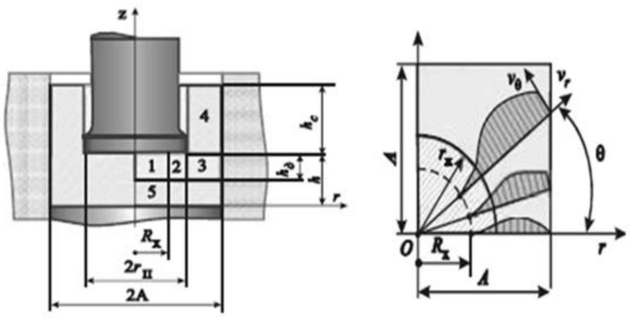
Based on (1), we can write:

$$\pi r_п^2 \cdot p v_n \sigma_s = \sum_{i=1}^{11} N_i \tag{3}$$

By substituting into the ratio (3) the value of the calculated power of the internal forces of resistance to deformation, contact friction and shear, which are calculated for each of the zones of the part - Ni, dividing the right and left parts by $vn\ \sigma s$ and the area of the working face of the punch πr_n^2 , after conversion to the criterion form, we find p

$$p = A_0 + A_1 h_\partial + A_2 / h_\partial \tag{4}$$

Values A0, A1, A2 are calculated constants. Ratio (4) is a mathematical model of the radial extrusion process (under the conditions $v_\theta = 0$). (4) can be considered as a function of the properties of the deforming material (σ_s), the dimensions of the workpiece and the tool (shown in Fig. 2), the friction conditions on the contact surfaces of the matrix and the punch (μ_1 and μ_2), as well as the varied parameter h_∂ - depth spread of plastic deformation center.



a) b)

Fig. 4. The diagram of the division of the part into zones (a) and the diagram of the three-dimensional flow in zones 2 and 3 (b) at the second stage of extrusion

Dependence (4) makes it possible to analyze the force mode of extrusion and the kinematics of the metal flow, determine the relative specific deformation force *p*, construct the velocity fields for zones 1 - 4, and use this data to calculate the total deformation force $F\partial$.

It is shown that the theoretical analysis of three-dimensional flow processes when $v_x \neq 0;\ v_y \neq 0;\ v_z \neq 0$ (or in the cylindrical coordinate system $v_r \neq 0;\ v_\theta \neq 0;\ v_z \neq 0$) (which is conventionally called "vortex", as recommended by A. G. Ovchinnikov [4]), can be carried out in full. The analysis performed the second stage, in which the wall formed by the overhang h_c with the festoon Φ acts as a rigid end and equalizes the velocity v_z along the angle θ. At this stage, the dimensions of the formed festoon no longer change (which is confirmed by experiments), and since the thickness of the wall along θ is variable, then this leads to a significant change in the character of the flow - the formation of a three-dimensional flow, in which we have $v_\theta \neq 0$ in zones 2 and 3 (Fig. 4, b). For a three-dimensional flow (when all components vr, $v\theta$ and vz are different from zero) the condition of constancy volume has a more complex form than with radial:

$$\frac{\partial v_r}{\partial_r}+\frac{\partial v_z}{\partial_z}+\frac{1}{r}\left(\frac{\partial v_\theta}{\partial_\theta}+v_r\right)=0. \qquad (5)$$

Equation (5) contains three unknown functions v_r, v_θ and v_z. If two functions v_θ and v_z are specified, then the function v_r can also be determined from the condition of constant volume. For this, you can use suitable functions that describe the flow of metal in zones 1, 2 and 3 (see Fig. 4, a). Zones 4 and 5 are hard, because in them all components of strain rates, except v_{z4}, are equal to zero. In addition, v_{z4} = const. Suitable functions must satisfy the boundary conditions. Zone 1 ($0 \leq r \leq R_x$) is characterized by a radial flow of metal, which is described by functions linear with respect to the independent variables r and z:

$$v_{z1}=-\frac{v_n}{h_\partial}[z-(h-h_\partial)];\quad v_{r1}=\frac{r v_n}{2h_\partial};\qquad v_{\theta 1}=0; \qquad (6)$$

where Rx – the unknown radius separating the regions of radial and three-dimensional flow.

Zones 2 and 3 ($R_x \leq r \leq r_п$, as well as $r_п \leq r \leq A/\cos(\theta)$) are characterized by an eddy flow that can be described by complex suitable functions. The velocities v_{z2} and v_{z3} are easily determined from the conditions of constancy of volume, and the function for the velocity $v_{\theta 2}$ can be given as a fit with five parameters (a_0, a_1, a_2, a_3 and λ) that must be varied to obtain min (F_∂):

$$v_{z2}=-\frac{v_n}{h_\partial}[z-(h-h_\partial)];\qquad v_{z3}=\frac{v_n}{h_\partial}[z-(h-h_\partial)]\frac{\pi r_n^2}{4A^2-\pi r_n^2}; \qquad (7)$$

$$v_{\theta 2}=[a_0+a_1 r+a_2 r^2+a_3 r^3](\sin 4\theta+\lambda\sin 8\theta)\cdot v_n;\quad v_{\theta 3}=v_{\theta 2}; \qquad (8)$$

where r, θ and z – independent variables; a_0, a_1, a_2, a_3 and λ – variable parameters.

It was established from previous experimental studies that $0 < \lambda < 0.55$. The functions v_{r2} and v_{r3} for zones 2 and 3 can be found from the condition of constant volume:

$$v_{r2}=-\frac{1}{r}\left[\int\left(\frac{\partial v_{z2}}{\partial_z}+\frac{1}{r}\frac{\partial v_{\theta 2}}{\partial_\theta}\right)\cdot r dr+C_2\right];\qquad v_{r3}=-\frac{1}{r}\left[\int\left(\frac{\partial v_{z3}}{\partial_z}+\frac{1}{r}\frac{\partial v_{\theta 3}}{\partial_\theta}\right)\cdot r dr+C_3\right]; \qquad (9)$$

Integrating (9) taking into account boundary conditions by zones leads to obtaining complex functions of the general form:

$$v_{r2}=f_r(a_0,a_1,a_2,a_3,h_\partial,\theta,\lambda,R_x);\qquad v_{r3}=f_r(a_0,a_1,a_2,a_3,h_\partial,\theta,\lambda,R_x), \qquad (10)$$

where R_x – variable, which allows to determine the border of zones 1 and 2, based on boundary conditions $0 \leq R \leq r_x$.

The velocity functions v_θ and v_r have the following properties: 1) the eddy current (when $v_\theta \neq 0$) starts from some coordinate $r = R_x$; 2) at the point $r = R_x$ function v_θ is continuous; 3) the metal of the workpiece does not penetrate through the wall of the matrix.

From these properties, we obtain additional information about the behavior of the corresponding functions v_θ, v_r and additional conditions: 1) at $r = R_x$ $v_\theta = 0$; 2) at $r = R_x$ we have $dv_\theta /d_r = 0$, as well as $d_2v_\theta /d_r^2 = 0$; 3) at $r=A/\cos(\theta)$ $v_{r3} / v_{\theta 3} = tg(\theta)$.

From these additional conditions follows the possibility to reduce the number of varied parameters by connecting them through 2 generalized parameters. This simplifies the process of minimizing function (4) depending on the depth of propagation of the plastic deformation center (Fig. 4), makes it possible to follow the transition of the deformation process from the initial stage (purely radial flow) to the second stage - three-dimensional flow, when $v_\theta \neq 0$ as an energetically more advantageous option with a sufficient height of the rigid end (extruded wall).

The accepted assumptions for determining the parameters of the functions v_θ and v_r, which minimize the function p (4), made it possible to perform calculations and describe the nature of the metal flow at all stages of extrusion with sufficient accuracy.

The strain rate intensity ξ_i is determined by the well-known formula, which contains the components of the strain rate tensor determined according to the Cauchy equations.

The obtained dependences for flow rates, deformation rates, intensity of deformation rates in each zone made it possible to describe the deformed state in the entire volume of the workpiece and proceed to the construction of a mathematical model of the process.

The power of the external deforming force applied to the punch:

$$N_{14}=F_\partial v_n = \pi r_n^2 \cdot p\, v_n\sigma_s \tag{11}$$

Based on (1), we can write:

$$\pi r_n^2 \cdot p\, v_n\sigma_s = \sum_{i=1}^{13} N_i \tag{12}$$

By substituting the values of the calculated capacities into expression (12), dividing its right and left parts by $v_n\sigma_s$ and the area of the working face of the punch πr_n^2, converting the obtained complex function to the criterion form, we find the relative specific deformation force p for extrusion in three-dimensional flow conditions [5].

The considered process is a process in which the radial and "eddy" currents flow sequentially. The MathCAD software package was used for the analysis and research of the process of metal pressure processing - a practical and effective tool that allows you to predict the nature of formation during metal pressure processing operations without the expense of experimental research.

The work analyzes the technological process of manufacturing a part of the "thin-walled glass" type with a variable wall thickness along the perimeter by cold reverse extrusion, as well as the influence of the CE parameters on the mechanical characteristics of this type of parts.

Conclusions and prospects for the development of the direction

1. The use of active forces of contact friction will reduce the specific force on the punch by 20-30%.

2. When choosing the optimal taper angle of the punch end, it is possible to reduce the specific force on the punch by 7 - 13%.

3. When choosing the optimal dimensions of the outline on the end of the workpiece, it is possible to reduce the specific force on the punch by 4 - 15%. Under the action of active frictional forces, the influence of the technological outline decreases.

All of the above factors increase the stability of the cold-drop tool (matrices and punches) by 40-45%. The stability of technological equipment directly affects the cost of production of blanks due to the significant costs of its production. Currently, in order to reduce the deforming force, various lubrication materials, tool shapes, methods of processing the surface of the workpieces are used, which allow to reduce the forces of contact friction, and extrusion with active frictional forces is also carried out. In addition, due to a significant improvement in the condition of the surface of the workpieces, the number of rejected products is reduced from 15% to 5%.

References

1. Vorontsov A.L. Theory of extrusion stamping / AL // M. Vorontsov: Mechanical Engineering 1, 2004. – 721p.

2. Cold forging / Ed. G.A. Navrotskogo. //M.:Mashinostroenie - 1987 – 384 p.

3. The theory of plastic deformation of metals / ed. E.P. Unksova, A.G. Ovchinnikov. - M .: Mashinostroenie, 1983 - 598 p.

4. Forging and Stamping: A Handbook. B-4 T .; m. 3. The cold forging / Ed. G.A. Nawrocki - M .: Engineering, 1989. – 368 p.

5. Analysis of extrusion processes under conditions of three-dimensional metal flow. / Krotenko G.A. NTU "KhPI" // Kharkiv, 2011 – 20 p.

Савицький Ю.В., Милько В.В., Бись С.С. Підвищення довговічності обладнання для холодного об'ємного штампування

В роботі вивчено процес холодного об'ємного штампування, який є дуже ефективним методом виготовлення заготовок деталей машин. При застосування холодного видавлювання відбувається швидке зношування високовартістної штампової оснастки та з'являються дефекти на готових виробах. Розробка раціональних технологічних процесів штампування сприяє вирішенню завдань по розширенню можливостей холодного видавлювання за рахунок зниження питомої сили, яка сприймається пуансонами, знаходження оптимальної форми пуансона, апробація різних марок сталей з метою їх підбору по найкращим експлуатаційним властивостям. Теоретично досліджено процес радіального видавлювання та побудовано його математичну модель на основі енергетичного методу, яка дозволяє провести аналіз силового режиму видавлювання і кінематики плину металу, визначити відносне питоме зусилля деформації , побудувати поля швидкостей для різних зон течії металу, а вже за цими даними розрахувати повне зусилля деформації. Розв'язок моделі дозволив сформулювати рекомендації по зменшенню виробничого браку та підвищенню довговічності штампового оснащення.

Ключові слова: течія металу, деформації, видавлювання, матриця, пуансон.