https://doi.org/10.31891/2307-5732-2025-351-77
УДК 621.77.01

MYHALEVICH VOLODYMYR
Vinnytsia National Agrarian University
https://orcid.org/0000-0003-1557-7331.
e-mail: mykhalevych@vntu.edu.ua
KOLISNYK MYKOLA
Vinnytsia National Agrarian University
https://orcid.org/0000-0001-5502-6556
e-mail: kolisnik30@gmail.com
SHTUTS ANDRII
Vinnytsia National Agrarian University
https://orcid.org/0000-0002-4242-2100
shtuts1989@gmail.com
HRYHORENKO NAZAR
Vinnytsia National Agrarian University
https://orcid.org/0009-0000-0694-5740
e-mail: 34grigorenko34@gmail.com

STUDY OF TECHNOLOGICAL PROCESSES OF STAMPING OF FLANGE-TYPE PARTS BASED ON THE APPLICATION OF COMBINED EXPRESSION METHODS

The research of technological processes for stamping flange-type parts, particularly using combined extrusion methods, is a relevant direction in the field of materials science and mechanical engineering. Flanges, as structural elements, are widely used in various industries, especially in mechanical engineering, where high quality requirements are imposed. Ensuring high quality and cost-effectiveness in production necessitates the development of effective stamping technologies that achieve the required mechanical properties and accuracy of the parts.

This paper examines the processes of combined extrusion, which integrate methods of bulk stamping and reverse extrusion. This approach allows for the simultaneous production of complex-shaped parts with enhanced accuracy and uniformity in the material structure. Such technologies ensure uniform deformation distribution and minimize the occurrence of defects, which is particularly important when manufacturing parts with high demands for reliability and durability.

Special attention is given to the optimization of the stamping process parameters, including the selection of suitable materials, geometric parameters of the workpieces, and processing modes. The use of numerical modeling made it possible to investigate the influence of these parameters on the final properties of the parts, thereby reducing the number of experiments and shortening the development time of new technologies. Additionally, the paper addresses the energy consumption of the process, tool wear resistance, and the influence of different technological modes on the material's microstructure. Thus, the research findings can be utilized to improve existing technologies and develop new methods for stamping flange-type parts, enhancing their market competitiveness and meeting the growing demands of modern production.

Ключові слова: stamping, rolling, material deformability, process modeling, analysis of technological parameters. Fig. 16. Ref. 22.

МИХАЛЕВИЧ ВОЛОДИМИР
КОЛІСНИК МИКОЛА
ШТУЦЬ АНДРІЙ
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Вінницький національний аграрний університет

ДОСЛІДЖЕННЯ ТЕХНОЛОГІЧНИХ ПРОЦЕСІВ ШТАМПУВАННЯ ДЕТАЛЕЙ ТИПУ ФЛАНЕЦЬ НА ОСНОВІ ЗАСТОСУВАННЯ СПОСОБІВ КОМБІНОВАНОГО ВИДАВЛЮВАННЯ

Дослідження технологічних процесів штампування деталей типу фланець, зокрема із застосуванням комбінованого видавлювання, має велике значення для матеріалознавства та машинобудування. Фланці є ключовими елементами різних конструкцій і широко застосовуються в авіаційній, автомобільній та енергетичній промисловостях. Їх основне призначення – забезпечення надійних з'єднань між компонентами конструкцій, що вимагає високої якості виготовлення та точності. Створення інноваційних методів штампування, які дозволяють отримувати деталі з покращеними механічними властивостями та мінімальною кількістю дефектів, сприяє підвищенню конкурентоспроможності продукції вітчизняного машинобудування.

Комбіноване видавлювання, яке поєднує об'ємне штампування та зворотне видавлювання, дозволяє створювати складні деталі з високою точністю та покращеною структурою матеріалу. Цей підхід забезпечує рівномірний розподіл напружень і деформацій, що мінімізує ризик виникнення внутрішніх дефектів, таких як порожнечі або тріщини. Це особливо важливо для виготовлення деталей із високими вимогами до надійності та довговічності. Оптимізація процесу передбачає вибір матеріалів із заданими характеристиками, визначення оптимальної геометрії заготовок і параметрів обробки, що знижує виробничі витрати та підвищує продуктивність.

Значну роль у цьому дослідженні відіграє чисельне моделювання, яке дозволяє передбачити вплив технологічних параметрів на кінцеві властивості деталей. Завдяки моделюванню можна оцінювати ефективність процесів без необхідності проведення великої кількості дорогих експериментів. Це не лише скорочує час впровадження нових технологій у виробництво, а й підвищує результативність науково-дослідницької роботи..

Ключові слова: штампування, обкочування, деформовність матеріалу, моделювання процесів, аналіз технологічних параметрів. Рис. 16. Літ. 22.

Стаття надійшла до редакції / Received 01.03.2025
Прийнята до друку / Accepted 22.03.2025

Statement of the problem

The main task of mechanical engineering in modern conditions is the production of high-quality products with minimal costs. The implementation of these requirements is facilitated by the use of resource-saving production processes, in particular volumetric stamping.

Products of complex configuration are widespread in the industry and are manufactured step by step by volumetric stamping methods, including extrusion. These processes are characterized by high specific loads on the tool and limitation of the range of products. To reduce the force of deformation during simple extrusion, the number of transitions is increased, the friction forces and the contact area of the tool with the workpiece are reduced. In addition, methods of local and combined deformation are used to reduce the deformation force.

For parts of a complex shape, the method of combined three-way extrusion is promising. This method allows you to significantly reduce the force of deformation and, as a result, increase the stability of the tool. Also, the number of transitions is reduced, due to which the number of stamping equipment is reduced and, accordingly, the cost of production is reduced. However, despite the advantages of using this method in the practice of stamping production, its practical development and mastering requires significant costs for technological training, since the search for rational modes of technological operations requires time-consuming experimental work to develop technologies. This is due to the lack of technological recommendations and methods of design and selection of technological modes of deformation with several stages of material flow. The disadvantage of such recommendations is the perceptibility of such developments in the process of extrusion of parts such as bushings with a flange and an axial process. Therefore, there is a need to carry out theoretical and experimental research to fill the existing gap and create scientifically based methods of designing processes for extrusion of parts of this type by the method of combined extrusion.

Analysis of recent research and publications

The development of science is closely related to increasing the practical use of its results in industrial and economic production. The most important factor in solving such tasks is the development of new technological processes that allow obtaining high-quality products with specified operational properties and with the lowest costs for their production.

A significant expansion of the technological capabilities of cold rolling stamping (CRS) is the development and implementation of processes that allow to significantly reduce the strength characteristics due to the regulation of the kinematics of the flow of metal and its stress state in the die cavity both with traditional CRS schemes and in combination with processes with forced localization center of deformation.

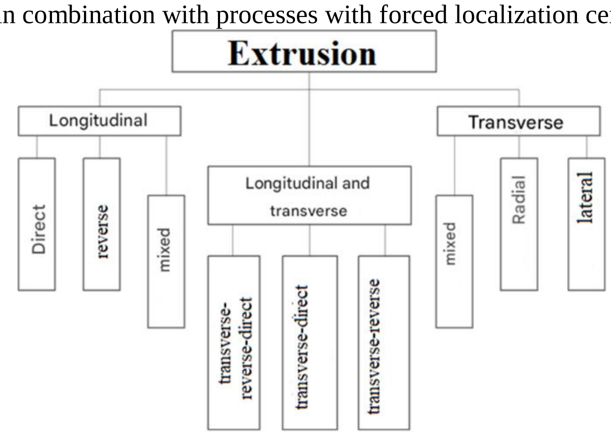


Figure 1 – Classification of extrusion methods

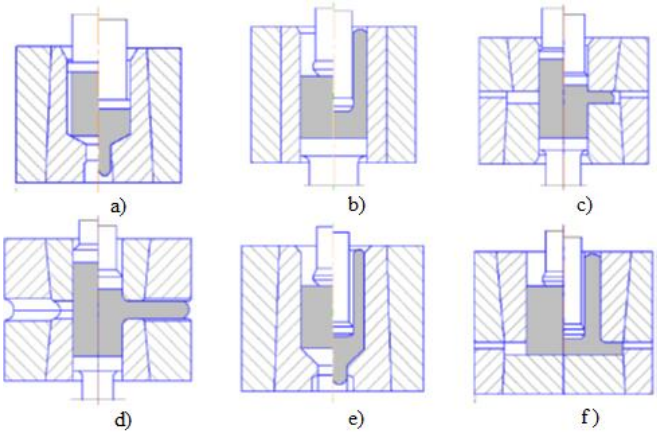


Figure 2 - Methods of cold extrusion (a - direct; b - reverse; c - transverse (radial); d - transverse (lateral); d - combined (reverse-direct); e - combined (radial-reverse)

It is possible to expand the nomenclature of stamped parts and the area of application of extrusion by mastering methods based on a combination of direct, reverse and transverse extrusion. For the implementation of stamping processes of complex parts, the development and wide application of various combined and combined processes, methods and devices for regulating the kinematics of the metal flow and its stress state in the stamp are necessary.

In [1], the upper estimation method of asymmetric combined extrusion processes is investigated. In this study, an analysis of the velocity fields was carried out, which determine the stamping loads, the extruded length, and the speed of metal distribution along the flow in the process of combined extrusion (Fig. 3).

The experiment was carried out on a lead sample at room temperature (Fig. 4). Stamping loads and extruded length were compared between theory and experiment.

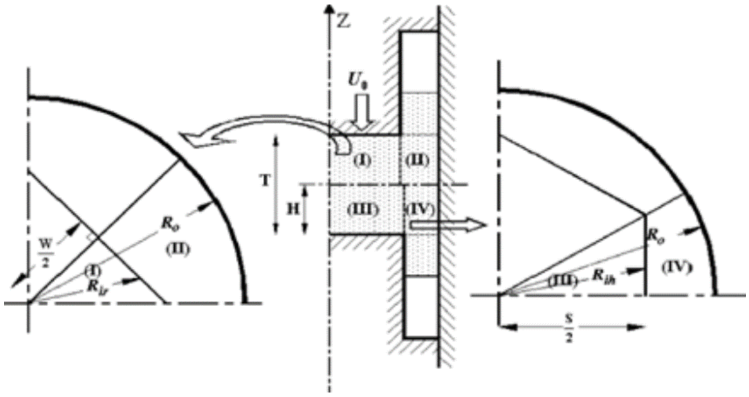


Figure 3 – Velocity field during extrusion

Figure 4 – Lead blank for the experiment

V. N. Levchenko in his research conducts numerical modeling of the process of combined extrusion, additionally calculates the processes of direct and reverse extrusion (Fig. 5). Based on the energy method, a mathematical model of the combined extrusion process was developed, which allows determining the energy parameters of the process as a function of the main parameters [2].

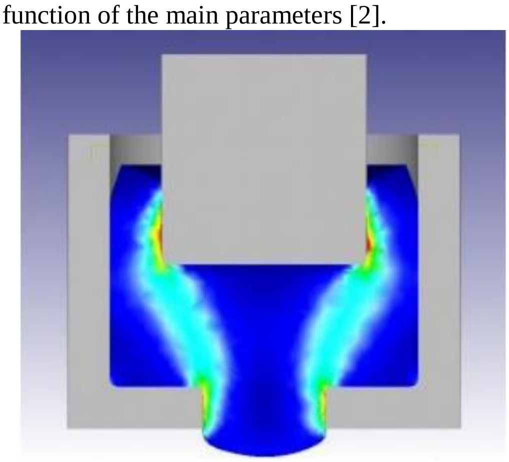


Figure 5 – Scheme of cyclic combined extrusion

In work [3], finite element modeling of the process of forming a sleeve-type workpiece with a combined flange was carried out using three-way extrusion. Control dependencies of the combined extrusion process due to changing the geometry of the working tool were obtained. A method of predicting a metal defect was developed and recommendations were given to prevent the appearance of this defect during the combined three-way extrusion of parts such as a sleeve with a flange.

The purpose and objectives of the research

The main goal is to develop methods that will improve the accuracy and quality of manufacturing flange-type parts, ensure uniform distribution of deformation, reduce deformation forces, and minimize the number of defects in finished products. The research is aimed at creating new effective stamping technologies that can be applied in modern materials science and mechanical engineering to improve production efficiency and quality.

The main results of the study

One of the effective methods for solving problems of plastic deformation is the energy method (EM), the main advantages of which are its flexibility, efficiency, and the possibility of effective application of EM to select the appropriate functions and varying parameters that describe the flow kinematics [3, 4, 5].

According to this method, a number of plastic zones of kinematic elements are distinguished in the deformed workpiece. After that, for each element, the kinematically possible velocity field (KPVF) is found and, based on it, the full deformation power, the simplification of which allows to clarify the estimates of the force regime and the picture of the plastic flow and to optimize the parameters of the deformation process.

$$v_z = c_1 \cdot z + c_2$$
$$v_r = -\frac{1}{2} \cdot c_1 \cdot r + \frac{c_3}{r} \quad (1)$$

where $c_1, c_2, c_3$are the sought variables.

To solve the problem using the energy method, it is necessary to divide the deformable workpiece into several zones of a simple shape and determine all the possible powers spent on deformation of the workpiece [6, 7, 8]. The power balance equation looks like this:

$$N_a = N_b + N_c + N_t \quad (2)$$

where N_a, N_b, N_c, N_t – power of active, deforming forces and forces of shear and friction.

Power of active forces:

$$N_d = \iiint_{V_{\ddot{a}}} \sigma_s \dot{\varepsilon}_i dV_{\ddot{a}} \quad (3)$$

where $N_d$is the power spent on deformation;

σ_s– stress intensity, MPa;

$\dot{\varepsilon}_i$– deformation intensity;

$V_{\ddot{a}}$– volume of deformation;

$dV_{\ddot{a}}$– an infinitesimal amount of deformation.

Deformation intensity:

$$\dot{\varepsilon}_i = \sqrt{\frac{2}{3}\left(\dot{\varepsilon}_r^2 + \dot{\varepsilon}_\theta^2 + \dot{\varepsilon}_z^2\right) + \frac{1}{2}\dot{\gamma}_{rz}^2} \quad (4)$$

where $\dot{\varepsilon}_i = \frac{dV_z}{dz}, \dot{\varepsilon}_r = \frac{dV_r}{dr}, \dot{\varepsilon}_\theta = \frac{dV_\theta}{r}, \dot{\gamma}_{rz} = \frac{dV_r}{dr} + \frac{dV_z}{dr}$are the rates of linear and angular deformations.

At the same time, the material compression condition must be fulfilled:

$$\dot{\varepsilon}_z + \dot{\varepsilon}_r + \dot{\varepsilon}_\theta = 0 \quad (5)$$

In order to exclude possible discrepancies when assessing the deformability of metals, it is necessary that the conditions of identity of the Nadai-Lode parameter, which characterizes the type of stress deviator, are observed in the studied technological process and experiments on the construction of plasticity diagrams:

$$\mu_\sigma = 2 \cdot \frac{\sigma_2 - \sigma_1}{\sigma_1 - \sigma_3} - 1 = \frac{2 \cdot \sigma_2 - \sigma_1 - \sigma_3}{\sigma_1 - \sigma_3} \quad (6)$$

The dependence of plasticity on the stress state scheme can be described by constructing the complete surface of plasticity in " $\varepsilon_i - \eta - \mu_\sigma$" coordinates.

The selection and substantiation of stress state invariants when solving problems of mechanics of materials is considered in the work of A. A. Lebedev and V. M. Mikhalevich [9].

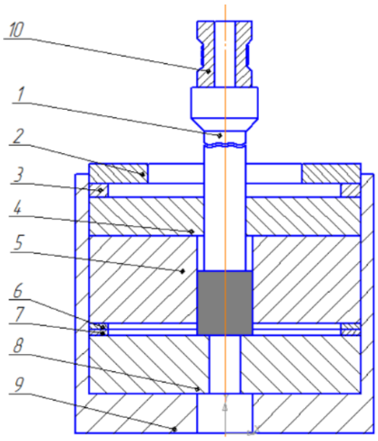
The work [10] proposed the construction of the plasticity surface in " $\varepsilon_i - \mu - \chi$ " coordinates, where $\chi$is an indicator that takes into account the third invariant of the stress tensor.

$$\chi = \frac{\sqrt[3]{I_3(T_\sigma)}}{\sqrt{3 \cdot I_2(D_\sigma)}} = \frac{\sqrt[3]{\sigma_1 \cdot \sigma_2 \cdot \sigma_3}}{\sigma_i} \quad (7)$$

The surface of plasticity, built in the coordinates " $\varepsilon_i - \mu - \chi$ ", can be defined as a three-dimensional diagram of plasticity.

In this work, experimental studies were conducted in order to obtain data confirming the adequacy of the selected calculation schemes and mathematical models of deformation, as well as to obtain a picture of the course of the material in order to determine shear deformations, logarithmic deformations and the intensity of deformations in the section.

To carry out the experiments, a design of a universal die (Fig. 6) for combined three-way extrusion was developed, and a set of equipment consisting of dies, punches, rings, counterpunches of the required geometric dimensions was manufactured.



1 – punch, 2 – lid, 3 – ring, 4 – centering ring, 5 – upper matrix, 6,7 – half rings, 8 – lower matrix, 9 – container, 10 – mesdose

Figure 6 – Scheme of a universal stamp

To account for the strengthening of AD31 materials, true stress curves were used, constructed based on the results of mechanical compression tests of cylindrical samples (Fig.7). Approximation of the hardening curves shown in fig. 7 was carried out by the static equation $\sigma_s = Ce^n$. The values of flow resistances at certain degrees of deformation are given in Table 1.

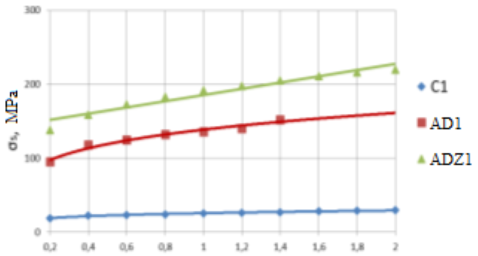


Figure 7 – Strengthening curves for the materials used

Table 1

Values of current resistances

e	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2
AD1	95	118	125	132	136	140	152	162	169	177
AD31	138	159	173	183	192	198	205	211	216	220
C1	19	22	23	24	25	26	27	28	29	30

With combined three-way extrusion, the presence of two centers of deformation with a hard zone between them is observed, which is balanced by an indicator that depends on the geometric parameters and the degree of deformation λ [11]. The upper center of deformation is formed by the reverse flow of material, and the lower center of deformation is the radial - direct flow [12]. A feature of radial-direct extrusion is the presence of a separation boundary of the material flow in two directions, which is described by a variable parameter - the radius R_k.

The task of combined three-way extrusion in two stages is considered. Upper the center of deformation is the reverse extrusion of the glass (Fig. 8).

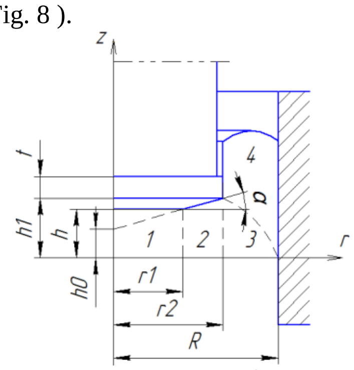


Figure 8 – Calculation diagram of reverse extrusion

Extrusion pressure, taking into account the chamfer on the punch, looks like this:

$$\bar{P}rev=\frac{1}{\sqrt{3}}\begin{bmatrix}\frac{\mu\cdot r_2}{12\cdot h}+\frac{h}{r_2}+\frac{R-r_2}{a}+3\cdot\mu+0{,}226+\frac{b}{r_2^2}\cdot\left(b\cdot ln\frac{a}{h}-0{,}5\cdot r_2\right)\cdot(8\cdot\mu-1{,}57)+\\+\frac{2}{R^2-r_2^2}\cdot\left[R^2\cdot ln\frac{R}{r_2}+2\cdot\mu\cdot t\cdot(R+r_2)+2\cdot a\cdot\left(\mu\cdot R+\frac{1}{3}\cdot\frac{R^3-r_2^3}{R^2-r_2^2}\right)\right]\end{bmatrix} \qquad (8)$$

where$a = h + 0{,}134 \cdot r_2; b = 3{,}73 \cdot h - 0{,}5 \cdot r_2$.

The lower deformation cell includes the induced pressure of the lower deformation cell from the scheme with rectilinear blocks.

The general diagram of the breakdown of deformation centers of combined three-way extrusion with the use of trapezoidal modules is shown in Fig. 9.

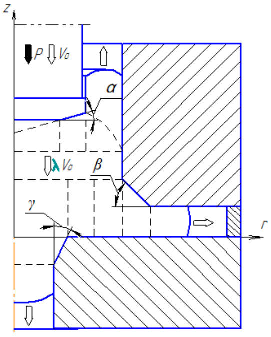


Figure 9 – Calculation scheme of combined three-way extrusion using the energy method with trapezoidal modules

Graphs of the dependence of the induced force on various geometric parameters for the scheme with trapezoidal modules are shown in Fig. 10 have a similar character to dependence graphs for rectilinear blocks [13].

Due to the decrease in the degree of deformation in the flange area and the decrease in friction between the flange and the matrix, the values of the induced force decrease depending on the increase in the height of the flange, which is shown in Fig. 10 a.

And with an increase in the circumferential degree of deformation and an increase in the friction contact surface, the values of the induced force increase depending on the relative radius of the flange (Fig. 10, b).

When the relative radius of the punch (Fig. 10 c) changes, the force values increase. I explain this by an increase in the friction surface and an increase in the degree of deformation in the reverse course of the material.

For schemes with kinematic trapezoidal modules, which take into account the presence of chamfers on the transition edges of the tool, the analysis of theoretical data showed a similar nature of the distribution of force indicators with a deviation of 7-10% to the side, which is associated with an increase in the volume of the deformation center and cut zones on the module boundaries.

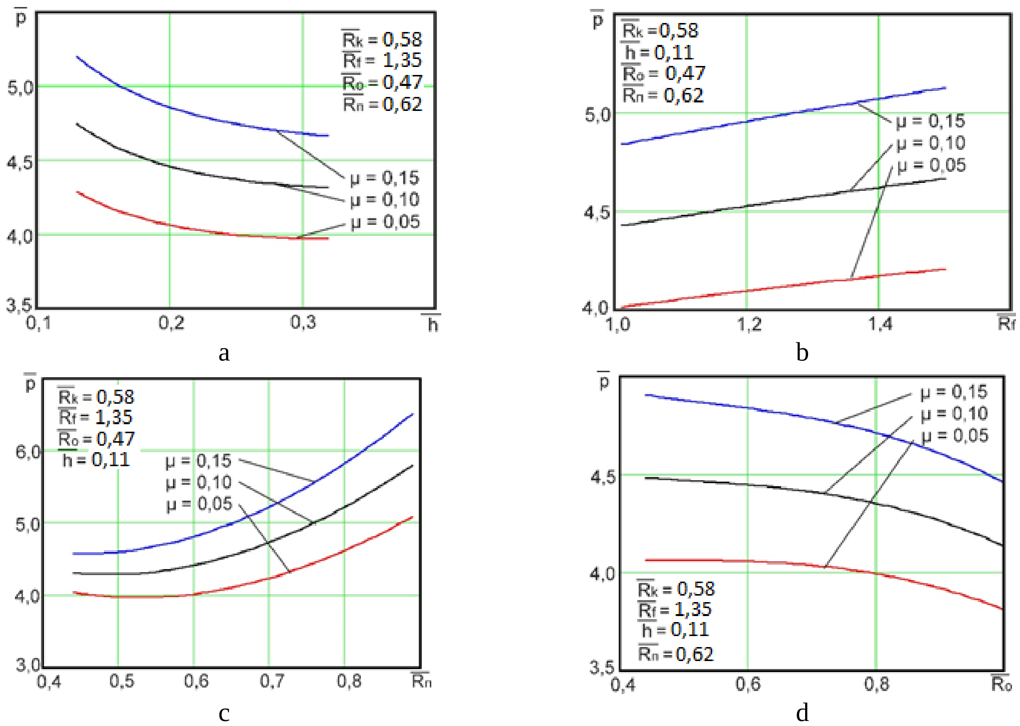


Figure 10 - Graphs of force dependence on the relative height of the flange (a), on the relative radius of the flange (b), on the relative radius of the punch (c) and on the relative radius of the process (d) at different friction values $\mu$of the scheme with trapezoidal modules

The step-by-step change in the deformed state when extruding hollow parts with a flange and an axial process in the "Deform-3d" package is shown in Fig. 11. It can be seen from the figure that the largest deformation occurs near the edge of the lower half-matrix when the process is obtained.

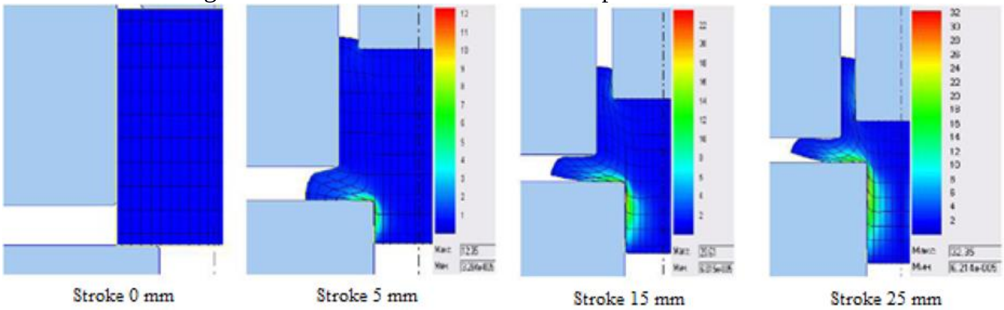


Figure 11 – Step-by-step change of the deformed state during the combined three-way extrusion of parts with a flange and an axial process in the "Deform-3d" package

In fig. 12 shows the dependence of the deformation force depending on the course of the punch. The decrease in force is associated with the reduction of the friction surface during the flow of metal in the radial direction, as well as with the delamination of the metal on the peripheral areas of the flange.

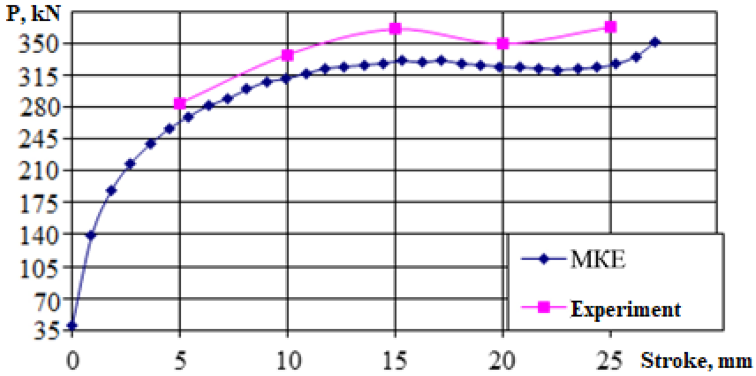


Figure 12 – Graph of the dependence of the deformation force on the stroke of the punch

In fig. 13 shows the reduction of the friction surface. It can be noted that as the punch moves, the contact surface between the extruded workpiece and the lower half-matrix decreases.

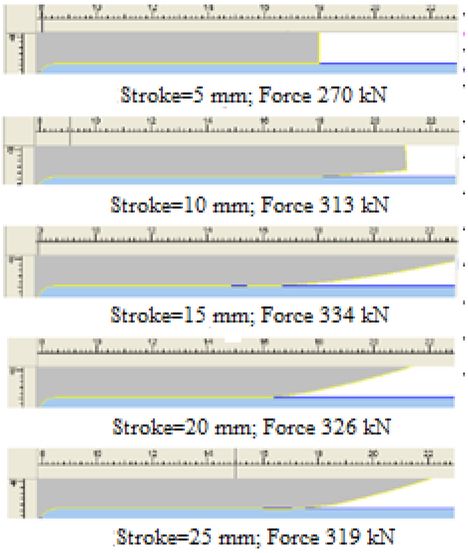


Figure 13 – Deviation of the flange shape in the process of deformation

Figure 14 shows the dependence of the deformation force on the radius of rounding of the edge of the hole of the lower half-matrix for different coefficients of friction [14, 15]. It can be seen from the graph that when the radius of rounding increases, the deformation force increases. Since a larger volume of metal is involved in the plastic zone.

To solve this problem, deformation with reciprocating flow of material to the process zone was applied.

For confirmation, an analysis using the finite element method was carried out, which qualitatively confirmed the assumptions (Fig. 15).

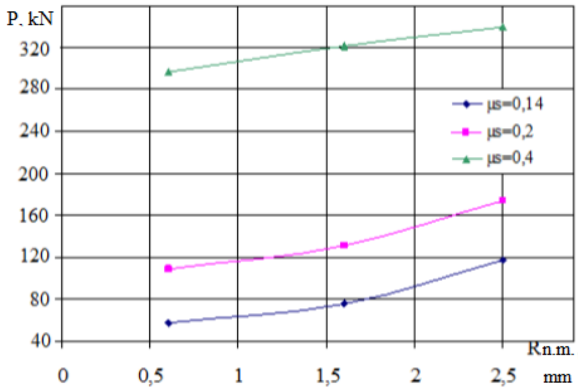


Figure 14 – Graph of the dependence of the deformation force on the radius of rounding of the edge of the hole of the lower half-matrix for different coefficients of friction

A comparative analysis of the processes of combined two-way and three-way extrusion was carried out. The Deform-3d software was used for the study [16, 17, 18] The following schemes of two-way extrusion were considered - reverse-direct, reverse-radial, radial-direct and scheme of three-way extrusion (Fig. 16). The initial dimensions of the blanks were assumed to be 45 mm in diameter and 45 mm in height. The geometric dimensions of the tool for all deformation schemes were assumed to be equal: the diameter of the process was 21 mm, the height of the flange was 5 mm, and the thickness of the glass wall was 4.5 mm.

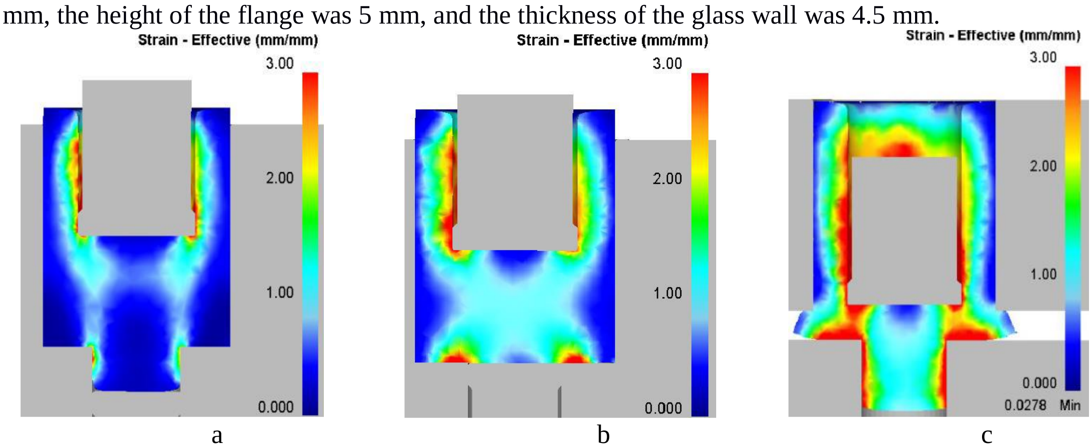


Figure 15 – Qualitative processing of the structure based on the proposed method (a – first stage; b – second stage; c – three-way extrusion)

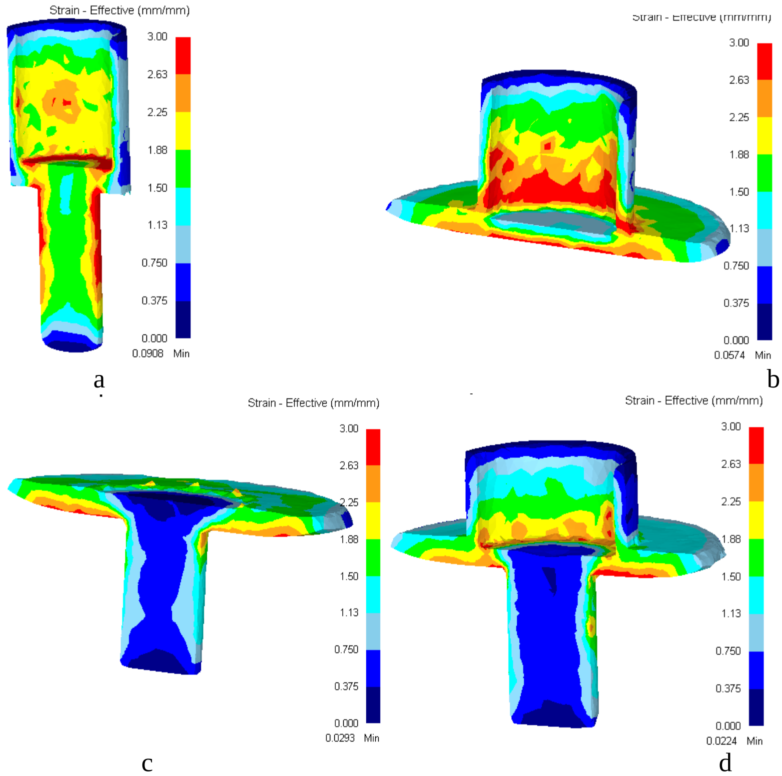


Figure 16 – The degree of deformation during combined extrusion: a – reverse-direct extrusion; b - reverse radial extrusion; c – radial direct extrusion; d – three-way extrusion

In fig. 16 shows the distribution of the degree of deformation along the cross-section of the workpiece. A more homogeneous processing of the material is observed during reverse-direct and radial-reverse extrusion. When using the combined three-way method of deformation, higher-quality extrusion of the flange part of the workpiece is observed [20, 21, 22].

Conclusions

A detailed study of the processes of stamping parts of the flange type using combined extrusion is presented, which is of great importance for modern mechanical engineering. Attention is focused on the relevance of the study, due to the growing requirements for product quality and the need to increase the efficiency of production processes. Flanges, as integral elements of structures in various industries, require the use of highly efficient production technologies that can ensure accuracy, mechanical strength and durability of products.

The study shows that combined extrusion is a promising method that allows to achieve high quality of manufactured parts. The main advantages of this method are the ability to produce complex parts with uniform distribution of deformation throughout the volume, which significantly increases reliability and resistance to wear. This is especially important for the production of parts that are subjected to significant mechanical loads during operation.

An important component of the work is the analysis of various aspects of the optimization of the rolling stamping process, including the choice of materials, geometric parameters of the workpieces, heat treatment modes and other important technological parameters. Thanks to numerical modeling, it was possible to predict the influence of these parameters on the final properties of the parts, which made it possible to significantly reduce the time and costs of conducting experimental studies. The use of numerical modeling plays a key role in the development of rolling stamping technologies that ensure consistently high product quality.

The use of the energy method for the analysis of deformation processes, which allows determining the kinematically possible velocity fields and optimizing the deformation parameters, is also considered. This approach enables more precise control over the stamping process and reduces the risk of defects in finished products.

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