chlorate and nitromethane separately are not explosives and only when the components are mixed, the composition acquires explosive characteristics. The explosive composition of the non-explosive components is offered to produce directly in the field of blasting, i.e. at the quarry. This will prevent the transport of explosive compounds from the manufacturer by the special transport on the territory of the country, because of the danger to the public, approval of the route with the traffic police or security threat of explosive cargo and reduce the amount of protected storage facilities for explosive materials on points at the quarry.

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Radial-direct extrusion with a movable mandrel

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Abstract

With the aid of grade grids method the character of strained condition and features of forming hollow parts when combined radial-direct extrusion were distinguished. By the upper- bound method the mathematical models of the radial-direct extrusion on the conical mandrel were developed. The estimation of the influence of geometric parameters on the power mode of the process was determined. The adequacy of developed mathematical models established experimentally.

Key words: RADIAL-DIRECT EXTRUSION, STRAIN STATE, UPPER BOUND, FORMING PRESSURE, HOLLOW PARTS

In a market economy is becoming increasingly important to use in engineering of new high technologies to produce competitive products. A certain part of the range of products of machine-building enterprises consist such products as housings, pipes, sleeves with complex (stepped) inner surface. Conventional methods of parts manufacturing of this type are heading, longitudinal (direct and reverse) and transverse extrusion, the local processing and stamping processes involving a combination of these methods. However, these methods are not effective at manufacturing of hollow parts with complex shapes and often when applying these methods the products with high metal intensity are obtained [1-3].

One of the promising areas of stamping technological development is assimilation of the combined extrusion methods of the figurine-shaped parts, based on a combination of the traditional schemes of the longitudinal extrusion with the transverse (radial and lateral) methods of extrusion in the tool having complementary degrees of freedom of movement [3, 4]. Increasing the shape complexity of parts produced in this way contributes to the growth of technical and economic performance and competitiveness of new technologies.

Radial-direct extrusion on the movable mandrel (Fig. 1) [5] is one of the way to significantly extend the possibility of stamping processes of the figurine-shaped parts. Fig. 1 b shows examples of products which can be produced by this method. The study of the extrusion process is important for science. It will allow us to expand the field of knowledge and gain new technical solutions having a practical application.

The objective of this work is to study the process of the combined radial-direct extrusion on the movable mandrel by formulating the mathematical models and experimental estimating of their adequacy.

a b

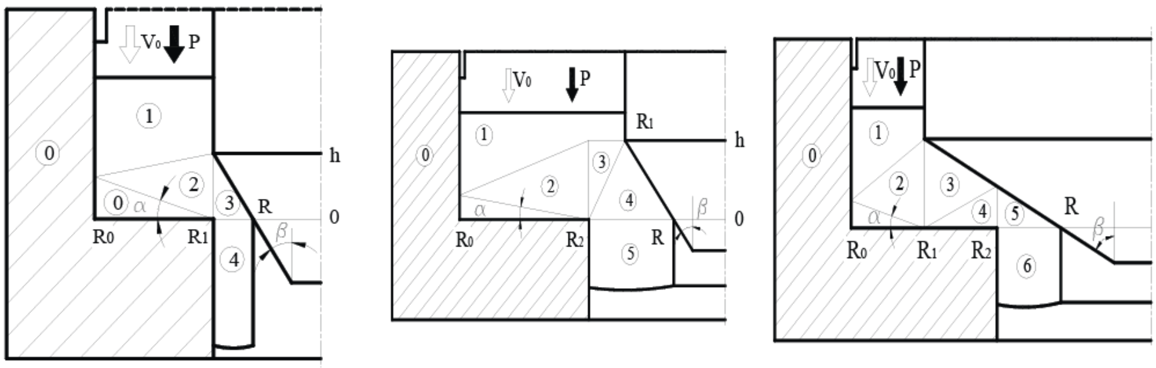
Figure 1. Scheme of the process (a) and parts (b) obtained by radial-direct extrusion

Shapes of the products that may be obtained by extrusion on the movable mandrel are various. The method is universal, that is by one and the same tool it is possible to obtain entirely different parts by adjusting of kinematics motion of the mandrel and the deformation punch.

Radial-direct extrusion on a movable conical mandrel has three special cases such as extrusion with zero gap between the mandrel and the matrix (Fig. 2a), a positive gap (Fig. 2b) and a negative gap (Fig. 2).

Theoretical study of the radial-direct extrusion on the mandrel is carried out by the energy upper bound [6-8]. Lay outs of the deformation zone for three particular cases are shown on Fig. 2. The reduced pressure of the radial-direct extrusion on the conical mandrel for three cases is shown in Table 1.

Formula of reduced extrusion pressure contain varying parameters such as the angles of optimization α and β, optimum values are determined from the pressure condition for minimum $\overline{p}$ numerically using MathCAD mathematical package.



a b c

Figure 2. Schemes of radial-direct extrusion on the conical mandrel with a lay out of the deformation zone (a - zero, b - positive and c - negative gap between the mandrel and the matrix)

Table 1. Formula of reduced pressure radial-direct extrusion on a conical mandrel

No	Formula	Scheme
1	$\bar{p}=\frac{1}{2\cdot(R_0-R_1)}\cdot\left(\frac{S^2+(h-Stg(\alpha))^2}{h}+\left(\frac{S}{\cos(\alpha)}\right)^2\cdot\frac{1}{h}+(ctg(\beta)-tg(\alpha))\cdot S+\frac{(R_0-R_1)\cdot(R_1-R)}{h}+2\cdot\mu\cdot((2H-S\cdot tg(\alpha))+\frac{S}{\cos(\beta)\cdot\sin(\beta)}+\frac{S}{tg(\beta)})\right)\cdot A_1$, where $A_1=-0.2713\cdot(S_1/S)^2+0.2339\cdot(S_1/S)+0.8679$, $S=R_0-R_1,\ S_1=R_1-R$	Zero gap (Fig. 2 a)
2	$\bar{p}=\frac{1}{2\cdot(R_0-R_1)}\cdot\left(\frac{(R_0-R_2)^2+(h-(R_0-R_2)\cdot tg\alpha)^2}{h}+\left(\frac{R_0-R_2}{\cos(\alpha)}\right)^2\cdot\frac{1}{h}+\frac{(R_0-R_2)(R_2-R_1)}{h}+(h-(R_0-R_2)\cdot tg\alpha)+\frac{h^2+(R_2-R_1)^2}{R_2-R}\left(\frac{R_0-R_2}{h}-tg\beta\right)+(R_0-R_1)\cdot tg\beta+2\cdot\mu\cdot((2H-(R_0-R_2)\cdot tg(\alpha))+\frac{R_0-R_1}{R_2-R}\cdot\frac{h}{\cos^2\beta}+\frac{R_0-R_1}{R_2-R}\cdot h)\right)\cdot A_2$, where $A_2=-1.3856\cdot((R_2-R)/(R_0-R_1))^2+1.7986\cdot((R_2-R)/(R_0-R_1))+0.3663$	Positive gap (Fig. 2 b)

3	$\bar{p}=\frac{1}{2\cdot(R_0-R_1)}\cdot\left(\frac{(R_0-R_1)^2+(h-(R_0-R_1)\cdot tg\alpha)^2}{h}+\left(\frac{R_0-R_1}{\cos(\alpha)}\right)^2\cdot\frac{1}{h}+(ctg\beta-tg\alpha)\cdot(R_0-R_1)+\sqrt{(R_1-R_2)^2+\left(\frac{R_2-R}{tg\beta}\right)^2}\cdot\sqrt{(R_0-R_1)^2+(h-(R_0-R_1)tg\alpha)^2}\cdot\frac{R_0-R_1}{(R_2-R)\cdot h}+\frac{R_0-R_1}{tg\beta}+(R_0-R_1)\cdot tg\beta+2\cdot\mu\cdot((2H-(R_0-R_1)\cdot tg(\alpha))+\frac{(R_0-R_1)\cdot(R_1-R_2)}{R_2-R}\cdot tg\beta+\frac{(R_0-R_1)(R_1-R_2)}{h}\cdot\frac{1}{\sin^2\beta}+\frac{R_0-R_1}{\sin\beta\cdot\cos\alpha}+\frac{R_0-R_1}{R_2-R}\cdot h)\right)\cdot A_3$, where $A_3=0.3293\cdot((R_2-R)/(R_0-R_1))^2-0.7317\cdot(R_2-R)/(R_0-R_1)+1.2023$	Negative gap (Fig. 2 c)

According to the results of calculations the diagrams of dependency of the reduced pressure $\bar{p}$ from the geometrical parameters of the process of the radial-direct extrusion on the conical mandrel and friction conditions (formulas without correction factors A1, A2, A3), part of which is shown in Fig. 3. When building the plots in the formulas of reduced pressure instead of the absolute values of the processes geometric parameters the relative geometrical parameters were used ($\bar{R}=R/R_0$, $\bar{R}_1=R_1/R_0$, $\bar{R}_2=R_2/R_0$, $\bar{h}=h/R_0$, $\bar{H}=H/R_0$).

Analysis of the dependences has shown that the most energy-intensive is the scheme of extrusion with a negative gap, the least energy-intensive with a positive gap, due to the degree of the deformation, which the billet obtains when extruding.

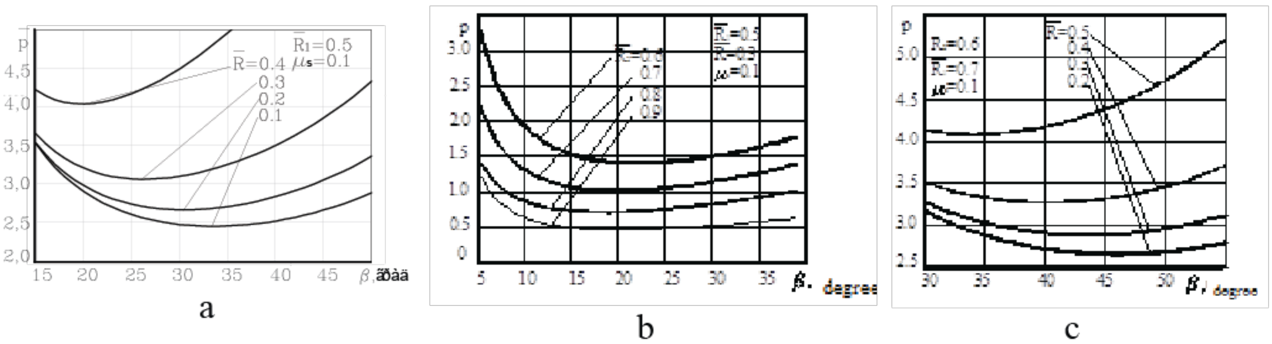


Figure 3. Plots of the reduced pressure of the radial-direct extrusion (for schemes a – with zero, b – with positive and c - with negative gap between the mandrel and the matrix)

It has been established that from the relative geometrical parameters on value $\bar{p}$ the greatest influence has the relative thickness of the extruded wall $\bar{S}_i=\bar{R}_i-\bar{R}$ and slope angle of the generator mandrel β. With the decrease of the parameter $\bar{S}_i$ the value of the reduced pressure increases which is associated with an increase in the degree of deformation. With the increase of the friction coefficient μ also the value of the extrusion reduced pressure increases proportionally $\bar{p}$.

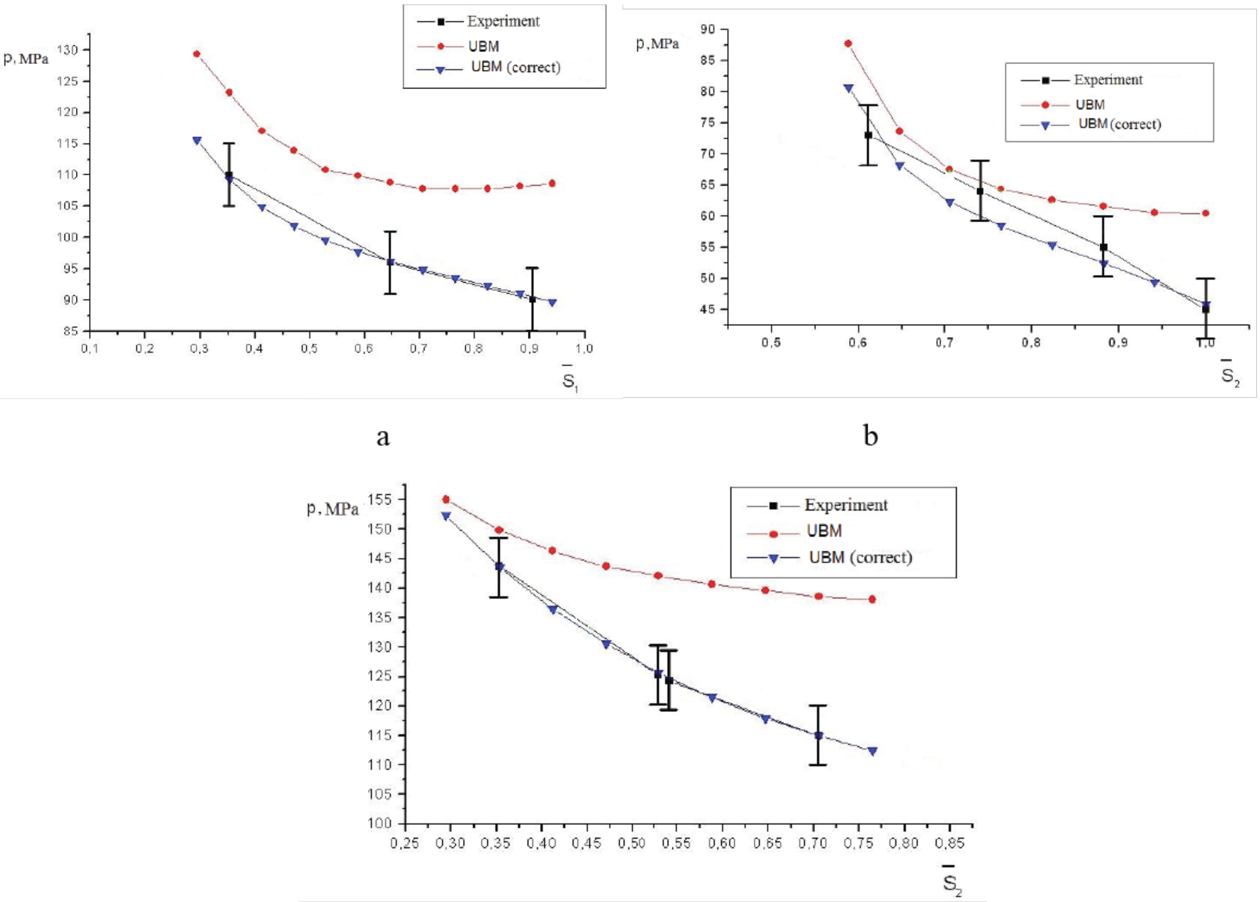
In order to check the adequacy of the mathematical models the experimental studies have been carried out on the extrusion of the hollow parts with variable thickness. The experiments have been performed in a specially designed universal flexible die.

The extrusion of parts made of materials S1 and AD1 was carried out. Plots that are demonstrating the dependence of the deformation pressure from the wall thickness of extruded parts determined experimentally and theoretically is shown in Fig. 4.

It was determined that for the scheme with zero gap uprateing the theoretical solution obtained by the upper bound on the experiment is in the range of 25% when extruding wall with the relative thickness from 0.35 to 0.88. It indicates certain inaccuracies of the developed mathematical model and the need to introduce correction factors. Data obtained by the corrected formulas UBM give deviation from experiment to 5%.

For schemes with a positive gap overrating of the solution obtained by the upper bound on the pressure on the experiment is up to 20% when extruding wall with relative thickness from 0.64 to 1.0. It indicates the adequacy of the developed mathematical model in this size range. The pressure values obtained by the formulas of corrected UBM give deviation from experiment to 5%.

For the scheme with a negative gap overrating solution obtained by the upper bound on the experiment is within 30% when extruding wall with thickness from 0.35 to 0.7, which also necessitates the correction of obtained model. Deformation pressure values are obtained by the formulas of the corrected UBM and deviates from experimental up to 2%.



c

Figure 4. The plots of the dependences of the deformation pressure from the extruded wall relative thickness to the scheme: a - with zero gap, b - with the positive gap and c - with the negative gap between the mandrel and the matrix.

The study of the deformed condition of the billet in the process of radial-direct extrusion by the method of grids has been carried out. Results as the field of intensity distribution of the logarithmic deformation in the transverse section of the billet are shown in Fig. 5.

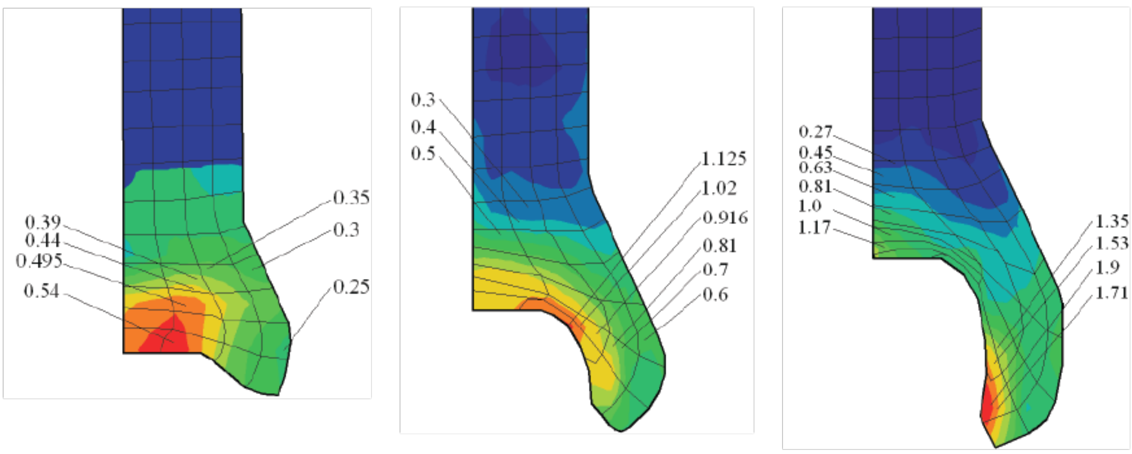


Figure 5. The fields of the intensity distribution of logarithmic deformations when radial-direct extrusion on the conical mandrel

The study of coordinate grids (Fig. 5) at different stages of extrusion process showed that the nature of the metal flow is uniform. At the initial stage the plastic deformation is concentrated in the areas limited by parabolic surfaces, conventionally designated in Fig. 1 b by lines. Located between these surfaces the metal volume has more intense deformation and the outer portion of the billet obtains a small plastic deformation or elastically deformed.

The study revealed that the distribution of deformation on the deformation zone is not uniform: the most deformed areas are adjacent to the transition edge lying on the matrix. This suggests that the area is dangerous and requires special attention in the design of tooling and process.

Therefore, when designing technology in order to reduce deformation values in the critical areas attention should be paid to the geometry of the transition edges, namely, to perform them with large radii of curvature.

In the development of the process of the radial-direct extrusion on the movable conical mandrel some new processes have been proposed. One of which is a semi-continuous extrusion of hollow parts with variable wall thickness Fig. 6 [9].

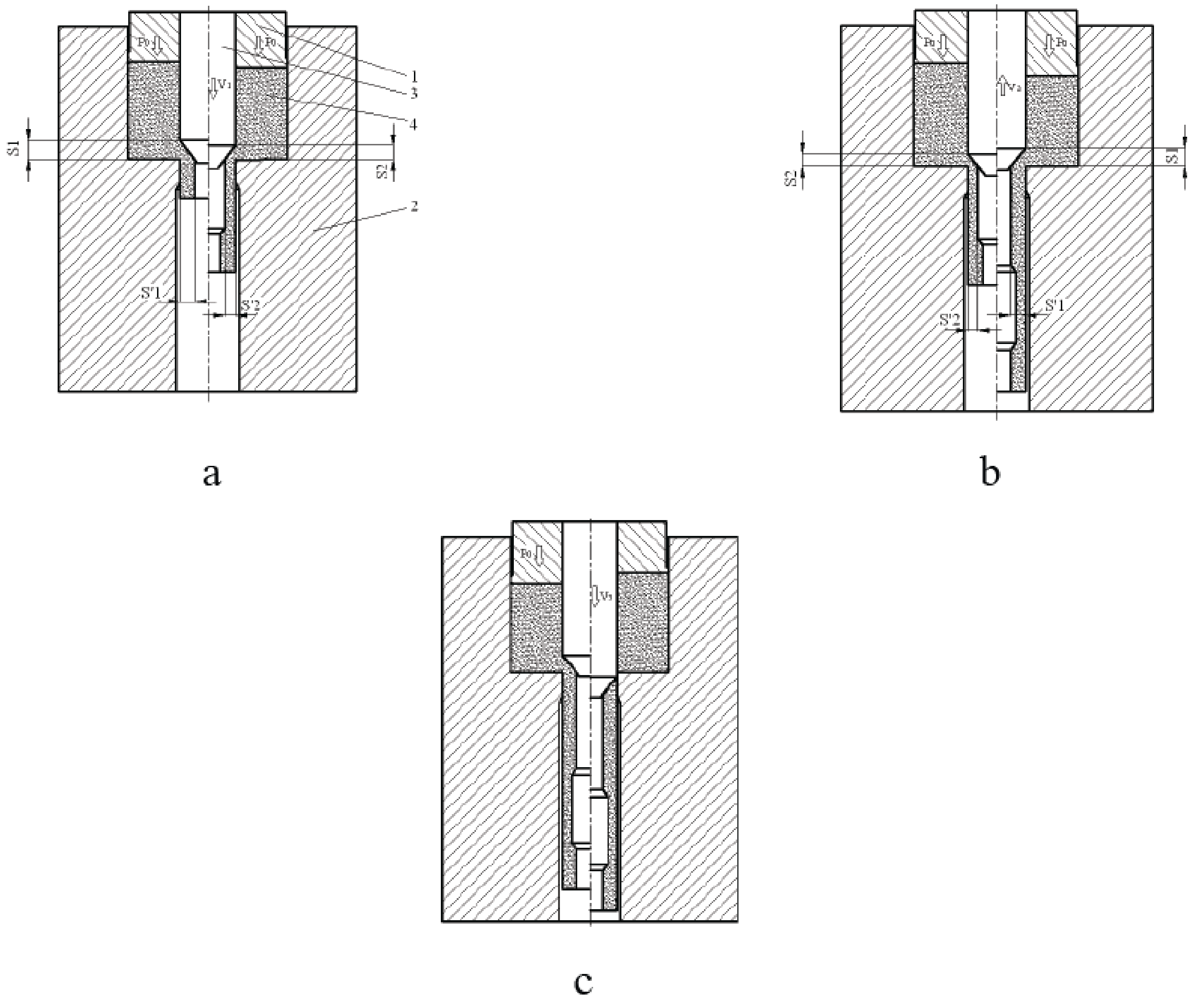


Figure 6. Transitions when a semi-continuous extrusion on the conical mandrel (a, b) radial-direct extrusion, (c) cutting of the extruded parts from the billet

This method is implemented by producing several parts from one multy-piece billet by semi-continuous radial-direct extrusion into the gap formed between the mandrel and the matrix. Separating finished part from the multy-piece billet is carried out in the area of changing the direction of the metal flow from radial to direct, by moving the mandrel relative to the matrix in the direction of punch movement when extruding. Moreover, the diameter of the mandrel and matrix is equal and process proceeds semi-continuously.

The proposed method makes it possible by varying the gap between the matrix and the mandrel to obtain such parts as sleeves with the variable wall thickness, which significantly extends the technological capabilities of the process and the range of stamped products. When extruding the hollow parts by this method the utilization rate of the metal increases due to decreasing of the remainder of billet parts in the metal amount of the one part, and the process efficiency increases by reducing the time of one part manufacture due to the removal of inserting operation of the new single workpice in the matrix for the extrusion of the following parts.

A method of producing figurine-shaped hollow parts with variable wall thickness [10] Fig. 7.

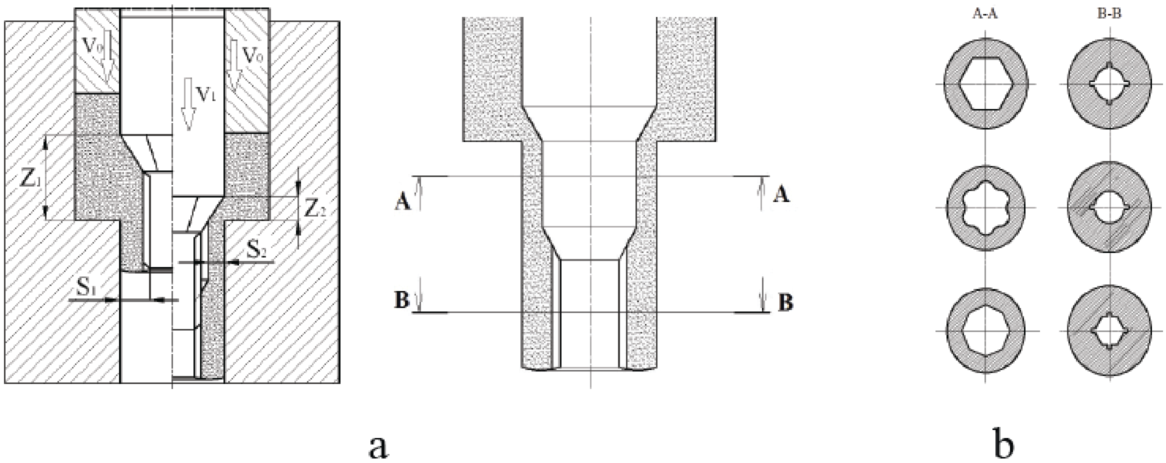


Figure 7. Transitions when extruding figurine-shaped parts on the moving mandrel (a) the scheme of extrusion on figurine-shaped mandrel (b) example of obtaining part

This method allows us to expand the range of the extruded parts.

This is provided by the fact that when the radial-direct extrusion on the mandrel the mandrel with complex profiles is used on its various sections located along its axis and when extruding the mandrel is moved positioning the profiled sections so that the metal that flows from deformation zone take the shape of the portion that is in contact with the deformation zone.

The inventive method allows for the use of the movable mandrel with complex profiles arranged at different parts of it which are located along the axis when radial- direct extrusion to obtain figurine-shaped parts such as sleeves with the variable wall thickness.

A method of making permanent joints is shown on Fig. 8-9. This method allows extending the range of products produced by the method of radial-direct extrusion.

The method is implemented as follows the multy-piece billet 1 and the core 2 are placed in the matrix 3. By adjusting the vertical position of the mandrel 6 and the conical sleeve 4 gaps Z1 and S1 are set between the mandrel and the matrix and between the core and the conical sleeve so that the thickness of the wall which will be extruded between the mandrel and the matrix is equal to the value of S1. Influencing by the punch 6 on the billet 1 the metal extrusion of the billet is carried out into the cavity formed between the mandrel 6 and the matrix 3, the diameter of the mandrel and the matrix are equal in magnitude. At the initial stage of the process the metal flows radially in the horizontal area and after reaching the angular flow direction alteration zone and contact with the mandrel it changes the flow direction at 90^0 and then flows parallel to the axis of symmetry along the inner surface of the matrix before the collision with a conical sleeve where it starts to flow along the core. When reaching the necessary stroke of the punch 7 and movement of the required volume of metal in the cavity formed between the matrix 3 and the mandrel 6 the gap between the mandrel and the matrix is increased to the value Z2 for the wall extrusion with thickness S2 where S2>S1. When desired stroke of the punch 7 has been reached permanent joint is separated from the multy-piece billet in the area of direction alteration from the radial metal flow to direct by downward shift of the mandrel 6 relative to the matrix 3.The cutting is done by interacting of the edges "K" of the mandrel and the matrix. After separation, the compounds are removed from the matrix, the mandrel is returned to its initial position and a new core is established in the matrix.

After the return of the mandrel 3 to the initial position the punch 1 continues to move down extruding the metal billet for processing of the following compound. Further extrusion continues cyclically to the full expenditure of metal volume of the initial multy-piece billet.

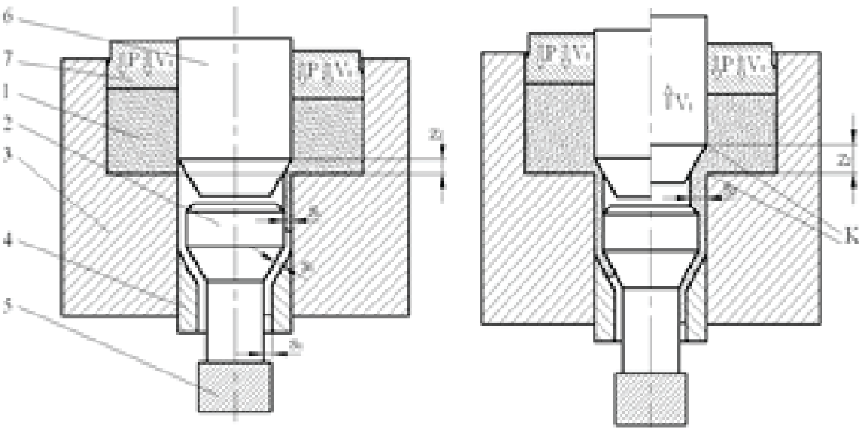


Figure 8. The radial-direct extrusion of the joint covering

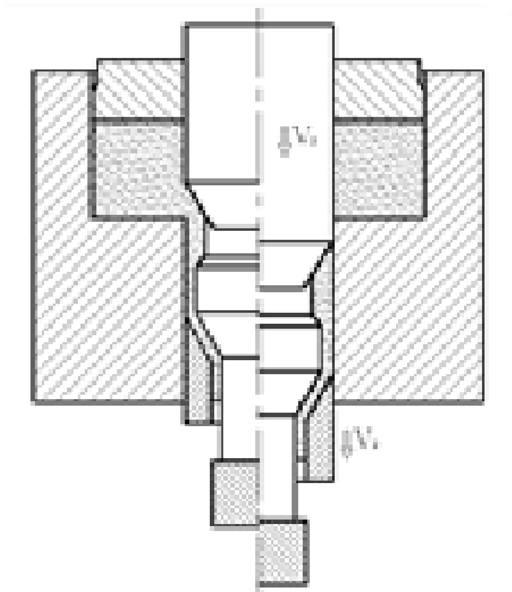


Figure 9. Cutting of the multy-piece billet covering

Conclusion

The deformation of the billet is assessed qualitatively and quantitatively. The effect of the tool geometric parameters on the distribution of deformations by volume of the part is studied. The results of researches of the deformed state by method of grids allowed specifying understanding of the deformation zone shape and size and identifying the areas with the maximum degree of deformation.

By the upper bound method the mathematical models of processes of radial-direct extrusion on the conical mandrel with zero, positive and negative gaps between the mandrel and the matrix are developed. The influence of the schemes geometrical parameters on the power mode of extrusion process is determined. It has been established that the developed mathematical models are adequate and give deviation on power ratings of the experimental data in average up to 5%.

The methods of extrusion allow obtaining parts of complex configurations with increased utilization coefficient of the metal. These methods are semi-continuous radial-direct extrusion allows obtaining a lot of the hollow parts with variable wall thickness from one multy-piece billet; the extrusion of the figurine-shaped parts allows to obtain the sleeve with variable wall thickness and different profiles at various sections of the part and method of making permanent joints.

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Echnological support of the gas-turbine engine parts bearing capacity by plastic deformation

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