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The Double-Sided Upsetting of the End Thickenings on Rod Blanks

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The known methods for the plastic shaping of axisymmetric parts with bilateral end thickenings and the die equipment used for their application have several significant drawbacks, which may reduce the quality of manufactured products, increase their cost, and limit the technological capabilities of production. As a rule, they provide alternate plastic shaping of end thickenings. In this paper, we propose a method of simultaneous stamping of end thickenings on a bar stock in split dies and a stamping device for its implementation. To establish the power modes of stamping we carried out the simulation of the process under study using the finite element method in the QForm software package. The dependencies of the stamping force on the geometric dimensions of the workpiece and friction conditions on the contact surfaces are established. The damageability of the workpiece material made of AA5056 alloy was assessed, and a diagram was obtained to determine the number of required stamping operations.

Keywords: cold forging, upsetting, end thickenings, force, material damageability

Highlights

- *A method is proposed for the simultaneous stamping of two end thickenings on a bar stock in split dies and a stamping device for its implementation.*
- *As a result of modeling, the nature of the influence of the geometric dimensions of the workpiece and friction conditions on the power mode of stamping was established.*
- *An assessment was made of the stress-strain state of the workpiece and the damage of the material at the final stage of stamping products from the alloy AA5056.*
- *A diagram was obtained to determine the number of necessary operations for stamping axisymmetric parts with end thickenings from AA5056 alloy.*

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0 INTRODUCTION

Axisymmetrical parts with end thickenings and axial cavities are widely used in various industries. In particular, they are used as pistons in pumping equipment, elements of axial power transmission in diesel, hydraulic hammers, and pneumatic devices, and for the movements of actuators in various automated systems.

One way to obtain axisymmetrical parts is by machining. However, the low metal utilization factor and significant production time do not allow this method to be considered rational for use in series production.

The most effective way to obtain this kind of part is by cold forming [1] to [6], which allows for obtaining parts with sufficient accuracy and minimal material loss. At the same time, productivity increases, and the resulting products have higher strength characteristics and wear resistance due to the hardening of the material.

The stamping of end thickenings can be performed using extrusion or closed die operations [7] to [10]. The thickening is formed, as a rule, on one of the product ends [11] and [12]. If it is necessary to obtain the thickening at both ends of the product, alternate plastic formations of end thickenings are used. In this case, complex stamping devices are employed, which require manual installation of blanks with pincers and removal of the forgings. Some devices have limited technological capabilities related to the size of the products, low productivity, and are not suitable for complex automation.

One promising direction in the development of forging and stamping production is the method of stamping by extrusion in split dies, the implementation of which is carried out both on universal equipment and on special presses. Unlike traditional stamping methods, the die has one or more parting planes, along which the parts of the die fit snugly against each other during the deformation of the workpiece. This method can be used for cold, semi-hot, and hot metal processing. The use of forging in split dies makes it possible not only to obtain forgings of a more complex shape with high dimensional accuracy but also to exclude the formation of a burr and its subsequent trimming, to reduce machining allowances, and to increase the productivity of forging [13] and [14].

Thus, it is relevant to develop a method for the simultaneous double-sided cold forming of end

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thickenings on rod blanks and study a stamping device for its implementation.

We propose below a design of a punching device with split dies. This model enables the simultaneous deformation of both end thickenings on a rod blank. The results of theoretical studies of the stressed and deformed state and damageability of the workpiece material made of AA5056 alloy are also presented hereafter in order to make it possible to determine the required number of forming operations.

1 TECHNOLOGY

The procedure of simultaneous moulding of the front and rear end thickenings (ET) should be focused more on the technological processes of plastic moulding of axisymmetric parts with bilateral end thickenings (APWBET) (Fig. 1).

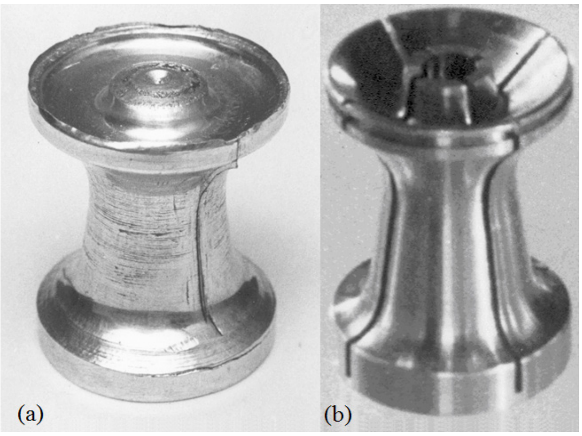

Fig. 1. *Axisymmetric part with end thickenings; a) before, and b) after machining*

The design of the stamping device should provide specified simultaneous moulding of ET in one stroke to make it possible to use conventional press equipment. This forming is carried out by upsetting the movable separable die 4 on the meridional plane (Fig. 2). In this case, geometrical dimensions, the shape of semi-finished product 2 before upsetting of ET, as well as its position relative to the tool (split die) at the moment of the beginning of plastic deformation, should be such as to ensure filling of both distant (from punch 1) ET in cavity 5 of a split die and distant (in the cavity 3) of the same die [13].

The production technology of the APWBET can include operations of cutting off measured rod billets, preliminary upsetting, or direct extrusion of the middle part of the billet, and the final stamping of end thickenings of various profiles [14]. The final dimensions of the product are formed by machining operations. If the through hole in the product has a small diameter, it is advisable to stamp a solid billet with further registration of the central hole by drilling. The metal loss, in this case, is insignificant. Depending on the degree of deformation, stamping can be carried out in 1 or 2 passes. The regulating factor is the accumulated damageability of the workpiece material, which should not exceed the permissible values. Let us consider the process of obtaining the billet APWBET at one stamping position, which will significantly increase the productivity of its production as a result of reducing the number of shaping operations and the exclusion of intermediate annealing.

2 RESEARCH METHODS

Theoretical studies of force regimes and the stress-strain state of the workpiece during stamping APWBET are carried out using the basic provisions of the theory of plasticity of a rigid-plastic, incompressible, hardening material in the QForm

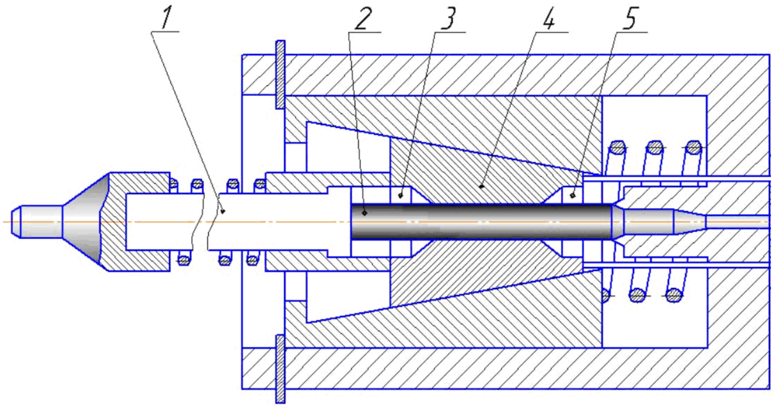

Fig. 2. *Simplified schematic of an upsetting device for simultaneous plastic forming of ET*

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2D/3D software package based on the finite element method. Conditions accepted: stamping temperature 20 °C; strain rate ξ = 1 s^{-1}; Siebel friction model; lubricant - mineral oil; friction factor 0.15; test materials: 1010, C27400, AA5056; the number of finite elements of the workpiece mesh is 30,000. The number of forming operations was determined based on the value of damage capacity accumulated by the billet material based on the phenomenological fracture criterion considering the history of deformation.

3 FORGING POWER MODES

To assess the power modes of stamping of the APWBET, a simulation in the QForm 2D/3D software package was carried out. Stamping is performed in a die with split matrices. A cylindrical blank of length l = 28 mm and diameter d = 14.5 mm is deformed by two punches moving in the opposite direction (Fig. 3). Under the influence of the tool, metal fills the cavities with the die, forming end thickenings. At the same time, an inner cavity is formed at the end of the workpiece, which serves as a marker for drilling a through hole (Fig. 4).

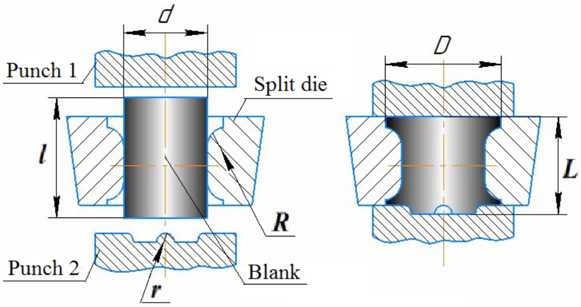

Fig. 3. *Schematic of the operation*

The workpiece material was assumed to be rigid, hardened plastic. The studies were performed for workpieces made of the following materials: 1010, C27400, and AA5056. The hardening curves of the studied materials are shown in Fig. 5 [15].

Fig. 6 shows the graphical dependencies of the change in the force of the operation on the relative movement of the tool where and h is the current and final movements of the punches, respectively.

At the initial stage of stamping, an internal cavity of the radius is formed at the end of the blank, which is accompanied by a slight increase in the deformation force. This is followed by the stage of metal accumulation in the cavities of the split die with the formation of end thickenings, accompanied by a smooth increase in the force.

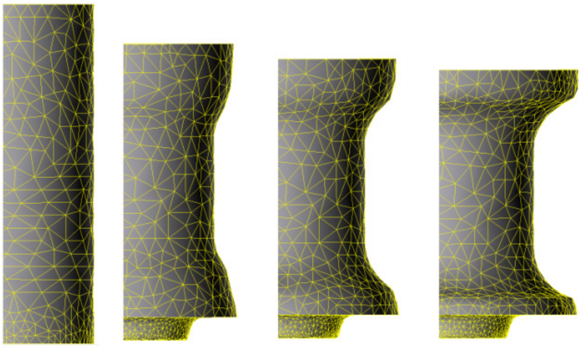

Fig. 4. *Sequence of shaping*

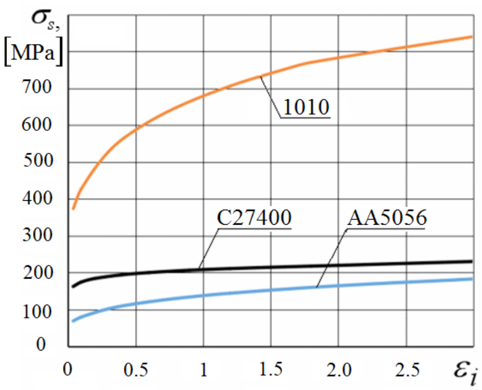

Fig. 5. Hardening curves of the studied materials
(t = 20 °C , ξ = 1 s^{-1})

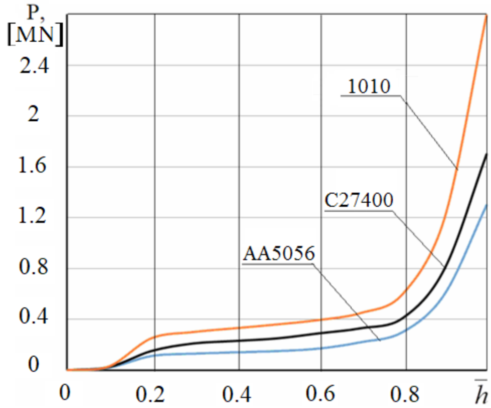

Fig. 6. Force-to-travel plots for stamping the APWBET
(μ = 0.1, R = 5 mm, r = 2 mm, d = 14.5 mm, D = 21.8 mm)

At the final stage, the final design of the contour of the workpiece by filling the angular sections of the die occurs, which is manifested by a sharp increase in the force of the operation. The technological force reaches its maximum value at the final moment of stamping $\bar{h} = 1$. In further studies, its maximum value is taken as the operation force. The main factors affecting the force modes of stamping of the APWBET are geometric parameters of the tool and workpiece: radius of curvature of the die cavity R, radius of curvature of the punch protrusion r, initial d and final D diameters of the workpiece, as well as friction conditions at the contact boundaries of the tool and workpiece, characterized by the friction coefficient μ. Theoretical studies of the forging force modes of the APWBET were performed in the following ranges of varying parameters: R = 3 mm, 5 mm, 7 mm, and 9 mm; r = 1 mm, 2 mm, 3 mm, and 4 mm; μ = 0.05, 0,10, 0.15, and 0.20. The diameter of the blank was taken as constant d = 14.5 mm, the diameter of the product mm, which corresponds to the values of the relative diameter. The length of the blank and the product were taken l = 28 mm, L = 22 mm. The results of the calculations are shown in Fig. 7.

It was found that the greatest influence on the force of stamping in the studied ranges of variation of varying parameters has a relative diameter. The decrease from 0.66 to 0.6, which corresponds to the increase in the diameter size of the product and, therefore, the degree of deformation with the unchanged dimensions of the blank, leads to an increase in the stamping force by 20 % to 30 %. The diametrical size of the product is determined by the requirements of the drawing and is not a subject of optimization of the force modes.

The radius of the inner cavities of the die R has a significant influence on the stamping force. Increasing R from 3 mm to 9 mm leads to a decrease in force by 15 % to 20 %, which is explained by more favourable conditions of metal flow with less energy required to change the trajectory. Increasing R, if allowed by the product drawing and operating conditions, leads to a decrease in force and increases the die resistance.

Increasing the radius r of the internal cavity at the end of the blank from 1 mm to 4 mm leads to an increase in force by 5 % to 10 %. The value of the specified radius is not significant in the design of the product because later, the central part of the blank will form a through hole, and the cavity formed during stamping, which is a marking, will be removed into the waste. Therefore, to reduce the stamping force, it is advisable to assign smaller values r. An increase in friction on the contact surfaces of the tool and workpiece can result in a 10 % increase in force. To reduce friction, it is advisable to use lubricants designed for this purpose and provide

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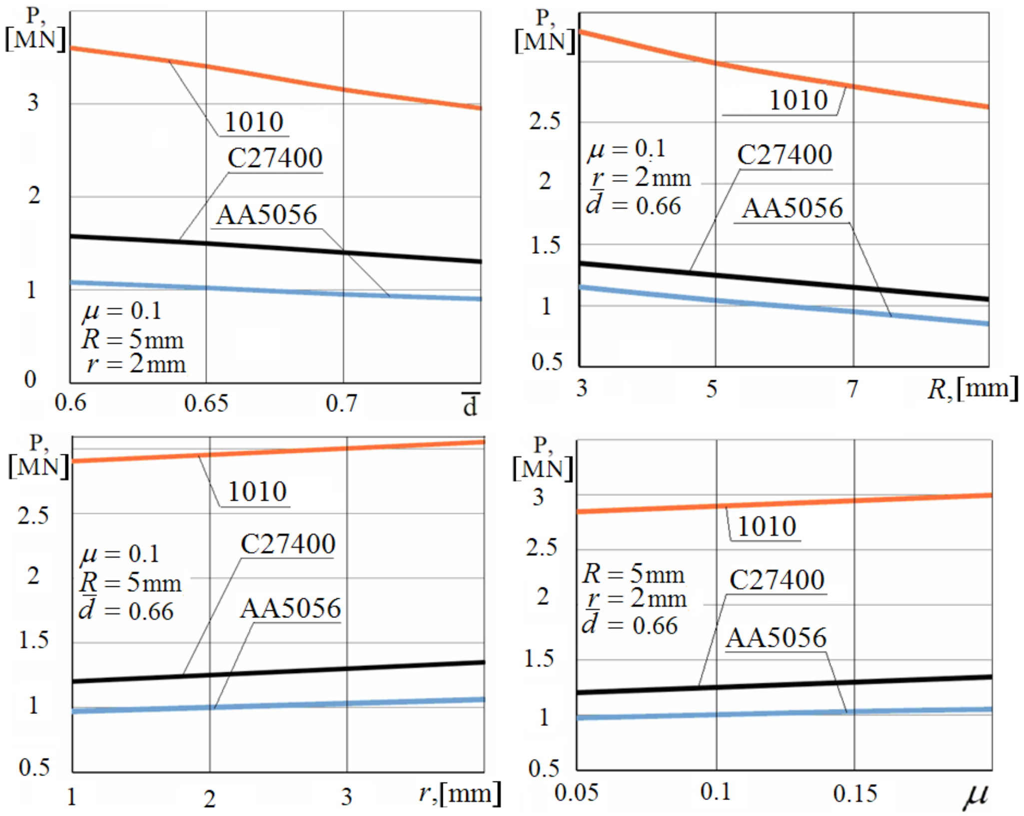

Fig. 7. *Forging power modes of APWBET*

careful treatment of the surfaces of the inner cavity of the die. During operation, it is necessary to monitor the condition of the working surfaces of the tool, to prevent wear and formation of scuffs, leading to an increase in force and deterioration of the appearance of products.

4 DAMAGEABILITY OF WORKPIECE MATERIAL

The processes of cold forging (CF) are characterized by high specific forces at significant degrees of deformation and are accompanied by significant strain hardening and accumulation of microdamage. The quality of products obtained by CF and the reliability of their operation depend on the level of accumulated damageability [16] and [17].

Material damageability ω during plastic deformation is often evaluated by the criterion proposed by Kolmogorov [17]. As a characteristic of material damageability, the degree of plasticity resource utilization is taken as a ratio of accumulated strain intensity to its limiting value on given characteristics of the stress and strain state of the elementary volume in the centre of plastic deformation:

$$\omega = \int_0^{\varepsilon_i} \frac{d\varepsilon_i}{[\varepsilon_i]} < 1, \quad (1)$$

where ε_i is the effective strain at a given stage of deformation; $[\varepsilon_i]$ is the effective strain at the moment of failure, depending on the stress state index.

$$\eta = \frac{3\sigma}{\sigma_i}, \quad (2)$$

where σ is mean stress, and σ_i effective stress. The value $[\varepsilon_i]$, as a rule, is found from experimentally obtained diagrams of ultimate plasticity.

To justify the number of necessary stamping operations, the stress and strain states of the blank in the process of forming were studied using the QForm 2D/3D software package. Fig. 8 shows the distribution patterns σ_i, ε_i, σ, and ω the final stage of the forging of APWBET of AA5056 alloy.

It was found that compressive stresses predominate in the deformation centre, which creates favourable conditions in terms of deformation without failure, contributing to the healing of micro-defects caused by plastic deformation and preventing the exhaustion of the plasticity resource of the material [16]. The greatest values ω are reached in the marginal areas of the end thickenings (points P_1 and P_2). Further studies were carried out on these points. Values σ, σ_i, and ε_i were calculated employing the QForm software package. The limiting values depending on η were set in the form of a data table for the corresponding

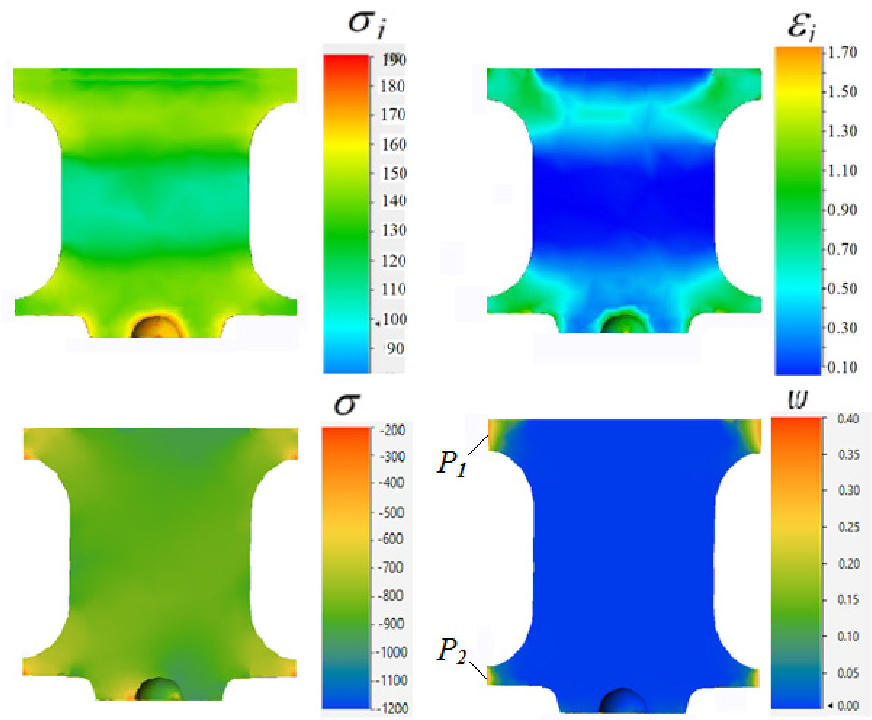

Fig. 8. Distribution σ_i, ε_i, σ, and ω at the final stage of stamping (material is AA5056 alloy; μ = 0.1, R = 5 mm, r = 2 mm, $\bar{d}$ =0.66)

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subprogram of the complex QForm according to the results of the approximation of the limit plasticity diagram [17]. An example of the calculation of the damageability for points P_1 and P_2 when stamping the APWBET of AA5056 alloy is shown in Fig. 9. The plasticity limit diagram $[\varepsilon_i]$ and the deformation trajectories at points P_1 and P_2 are shown. For the example under consideration, at point

$$P_1\text{:}\ \eta = -1.8,\ \varepsilon_i = 0.61,\ \varepsilon_{np} = 1.67,\ \omega = 0.36;$$
$$P_2\text{:}\ \eta = -1.6,\ \varepsilon_i = 0.47,\ \varepsilon_{np} = 1.61,\ \omega = 0.29.$$

It was found that the values $\bar{d}$ and R have the greatest influence on the damageability of the workpiece material. Their decrease in the studied range ω decreases by 30 % to 40 % and 20 % to 30 %, respectively (Fig. 10).

It was found that at values $\bar{d}$ < 0.62, the damageability of AA5056 alloy reaches a critical lev $\omega > 0.3$, which, according to the recommendations [16], is unacceptable for critical products. In this case, the stamping of the APWBET in one operation is impossible, and in the technological process, it is necessary to provide an additional transition of preliminary profiling - the upsetting of the end thickening of the cylindrical billet with subsequent annealing and the final dimensions are formed at the second operation (Fig. 11).

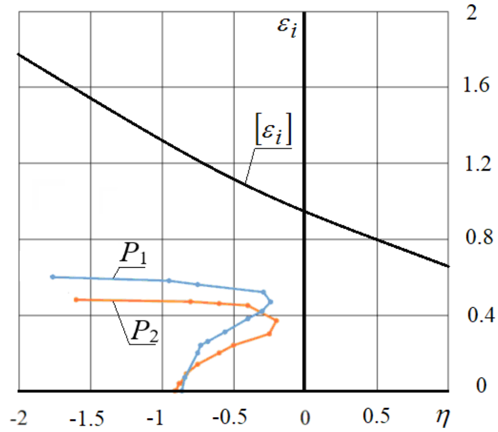

Fig. 9. *Assessment of the damageability of the material*

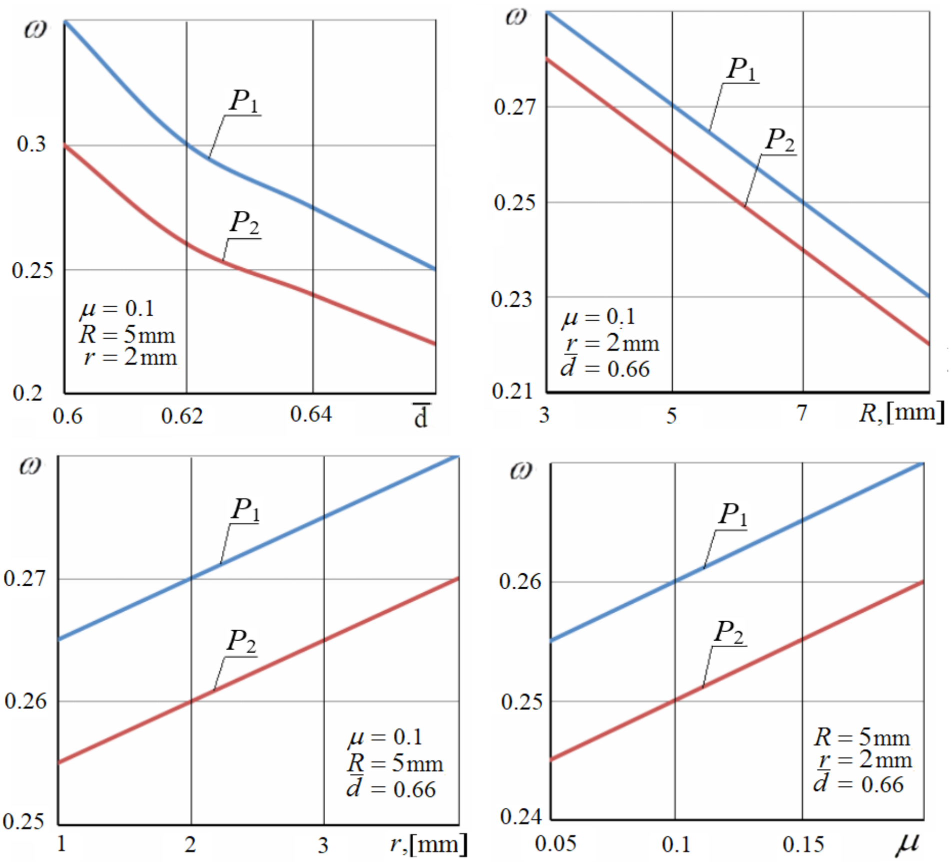

Fig. 10. *Damageability of the material when stamping the APWBET*

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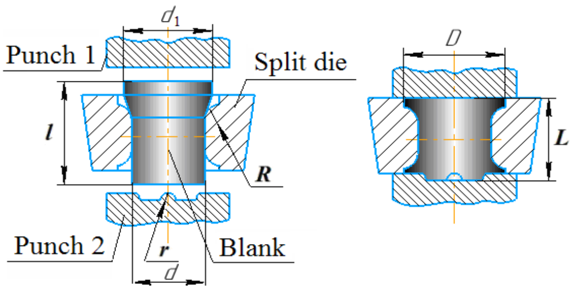

Fig. 11. *Schematic diagram of the forging of the APWBET from the profile billet*

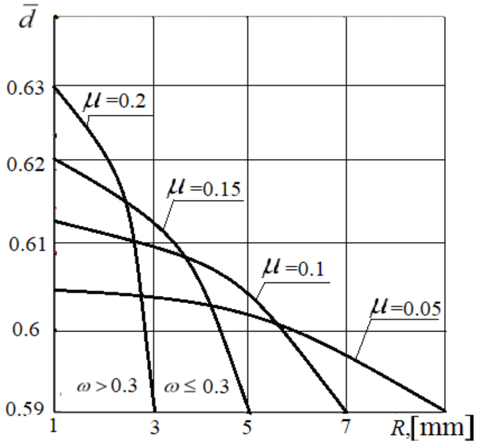

Fig. 12. *Determining the number of stamping operations (material - AA5056)*

When using a preformed billet with a diameter of the thickened part d_1 = 19 mm and length l = 25 mm, the damageability of the material at the final stamping operation is reduced, not exceeding the value ω = 0.25, which meets the requirements for products of the critical application.

Fig. 12 presents a diagram for determining the number of necessary forming operations when stamping the APWBET. The area of the diagram below each curve, corresponding to the coefficient of friction μ, at given $\bar{d}$ and R are characterized by the values of damageability $\omega > 0.3$, which means the necessity of the operation of preliminary profiling of the workpiece. In this case, the stamping is performed in two transitions. The area of the diagram over the above curves corresponds to the permissible values of damageability $\omega \leq 0.3$, which means that it is possible to obtain the product in one stamping operation.

Thus, with the given ratios of geometric parameters and the degree of deformation, the APWBET can be produced in one stamping operation with values of the degree of plasticity resource utilization acceptable for critical parts. When stamping the end thickenings of large diameter, it is necessary to use pre-profiling of the middle part of the APWBET to ensure rational kinematics of the flow of the deformed material and to reduce the damageability.

5 CONCLUSIONS

1. The stamping axisymmetric parts with end thickenings from a bar of continuous cross-section was proposed, expanding the technological capabilities of cold stamping of small, precise parts of complex shapes, providing increased productivity and reduced material losses.
2. As a result of modelling the stamping of solid APWBET from a cylindrical billet, we come to the conclusion that the factors influencing force modes of APWBET stamping are the geometric parameters of the tool and the billet: the radius of curvature of the die cavity R, the radius of curvature of the punch projection r, initial d and final D diameters of the blank, and also friction conditions at the contact boundaries of the tool and billet, characterized by friction coefficient μ. By doing so, a quantitative assessment of the influence of these parameters within the investigated range is given.
3. The assessment of the damageability of the blank material in dangerous points has been carried out. Thus, we establish the ranges of deformation degree and product geometry changes, at which the stamping of solid APWBET can be performed for one and two form-modifying operations.

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