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PHYSICAL MODELING OF TECHNOLOGICAL CHARACTERISTICS AT STRETCH FORGING OF BILLETS WITH ROTATION IN COMBINED DIES

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The method of intensification of deformation of billet or ingot for reaching of effect of macro-shift deformations during stretch forging in combined dies is grounded. The experimental analysis of form changing of billets at different modes of hot stretch forging was executed by physical models from lead. The method of experimental research of technological characteristics is developed applied to new conditions of stretch forging of billets by hydraulic presses. The best technological modes as quantities of reduction and angles of rotation of billet around axe are founded for approximation work-piece cross-section to round shape and getting resource saving effect.

Key words: stretch forging, combined dies, billet, physical models, form changing.

Introduction

Processes of forging of shaft forgings are very labour-consuming, and the operations of stretch forging occupy the major share of machine time of production. Changing of the sizes of the cross section and length of the forging at stretch forging is produced with different working tools [1]: flat dies, convex dies, cut-out dies, combined dies. The calibers of cut-out and combined dies can have rhombic or radius (round) profile. Forgings shafts, depending on the operating conditions of these products are subdivided into groups of process with a particular procedure of a mechanical test. Currently an active development of innovative ways of forging, which let intensify the deformations at low coefficients of the total reduction of cross-section, and the main mass of them is connected with the implementation of macro-shifts of work-piece material [2]. From the perspective of waste minimization in further fine-tuning to the size of forgings parts it is necessary to comply with the geometrical precision of forgings of round cross-section by machining operations.

Analysis of recent researches and publications

In work [3] was proposed to implement an intermediate forging of large forgings with profiled dies, allowing compressing of ingot for a three-beam and a four-beam billet. Further broaching from a profiled billet, accompanying by the formation of round cross-section of forging due to macro-shift, requires the tool change that may cause cooling and necessity of additional heating of the ingot. Furthermore, for obtaining of three-beam and four-beam billets various sets of the working tools are used. The technological realization of the method [4] involves forging of a billet at first with flat dies and then it's spinning around a longitudinal axis in dies with a round cutout without the increasing of the length of the shaft. Studying of broaching of ingots with profiled dies was discussed in an article [5], which also analyzed the conditions of changing of a billet size and macro-shifts beginning. According to the method [6], shafts produce broaching with gripper at first one end, then the other end of the ingot. In this case a special lower die is turned along the feed of forged billet and broaching is made along the length. The repetition of this cycle provides the forging of formed profiled billet with ensuring macro-shifts effect. But it is clear that the achievement of a positive impact of macro-shifts effect on quality indexes of forgings due to complications or increase the number of tool sets is economically justified only in forging of ingots of high- priced alloyed steel grades.

It is necessary to pay attention to the method [7], according to which the achievement of macro-shifts in forging of shafts of round or polygonal cross-section in round or rhombic cut out dies by varying of modes of reduction and rotation of the ingot around the longitudinal axis was established. But in this case the modes of combination of quantities of reduction and angles of rotation, which are optimal for achieving of elaborated work of the ingot in cross-section, or in getting the best indicators in geometry (from the point of view of approach of the cross section to a round shape) remain unknown.

Taking into consideration, that the use of a universal tool allows to reach a wider range of forged products, the research should be aimed precisely to development of innovative modes of forging of billets spread in manufacturing combined dies. Such studies initiated in works [8, 9] applied to the conditions of a forging shop at Company Ltd. "METINVEST - Mariupol Mechanical Repair Plant", organized on the basis of a unit of repair shops PJSC "Mariupol Ilyich Iron and Steel Works" (Ukraine). By methods of finite element modeling the peculiarities of stress-strain state of forgings shafts at forging have been indicated [8], as well as the regularity of the influence of the amount of reduction on kinematical characteristics at stretch forging of billets in combined dies with a round shape of cut-out has been set up [9]. The development of scientifically well-founded recommendations in the choice of rational modes of stretch forging in these dies at the expense of implementing of the schemes of intense deformations requires an experimental study of the influence of quantities of reduction and angles of rotation of the billet around the longitudinal axis to the geometric characteristics of the cross-section and study of the material strain to ensure the production of forging-parts with an elongated axis and with the necessary performance exploitative characteristics.

The purpose of the research

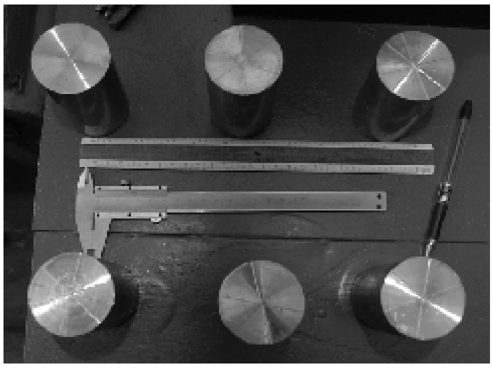
The aim of the present study is an experimental study of the forming and force parameters at different modes of stretch forging of cylindrical billets with rotation around the longitudinal axis in combined dies.

To achieve this aim the task has been formulated. To determine the coefficients of reduction of billets, changes in the geometric characteristics of the cross-section from the point of view of its approach to a round shape and distribution of the force parameters on modes of stretch forging with different parameters of upsetting and angles of rotation of billets around the longitudinal axis.

Materials and methods

Six samples with diameter D_0 = 50 mm and length L_0 = 100 mm were produced from antimonide lead (2 % antimony). Samples were produced by extrusion and were labeled at one end with labels "0", "1", "2", "3", "5", "8" (fig. 1, a), and at the other end marks were applied to perform rotation around the longitudinal axis of the work-piece at fixed angles $\Delta\varphi$ = 30°, 60° and 90° (fig. 1, b). Before the stretch forging performing the length of billets L_{0y} was refined by measuring with a caliper.

a



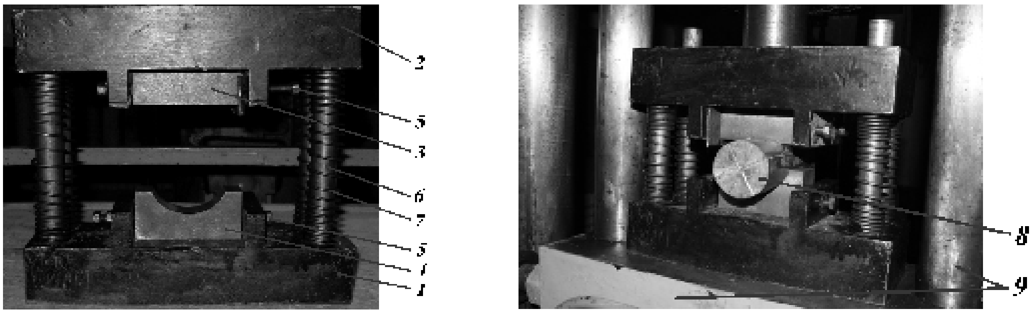
b

Fig. 1 – Initial samples:
a – marking at one end;
b – marking-out of angles of rotation on the other end

The model of cut-out dies were made for laboratory experiments in scale 1:10 to the size of a productive nature: width B_m = 30 mm, the radius of the notch in the lower die R_m = 30 mm. The material of dies is steel 45 (0.45% carbon). These dies were fixed in a stamp block (fig. 2, a), mounted on a universal testing machine (0.2 MN), and carried out the deformation of lead samples (fig. 2, b) with the entire width of the die in the middle of the length of the work-piece (which corresponds to the amount of feed ΔL = 30 mm, the relative feed rate $\psi = \Delta L / B_m$ = 1,0). So, the influence of hard not deformed ends at modes of running forgings was also taken into account (fig. 3, a, b), which receives the stretch in the longitudinal direction due to making compressions. In real conditions it is necessary to remove the work-piece along the front of feed with relative feed $\psi \leq$ 1,0 and hold running along the diameter, having the given values of upsetting and angles of rotation for the implementation of the next step of stretch forging.

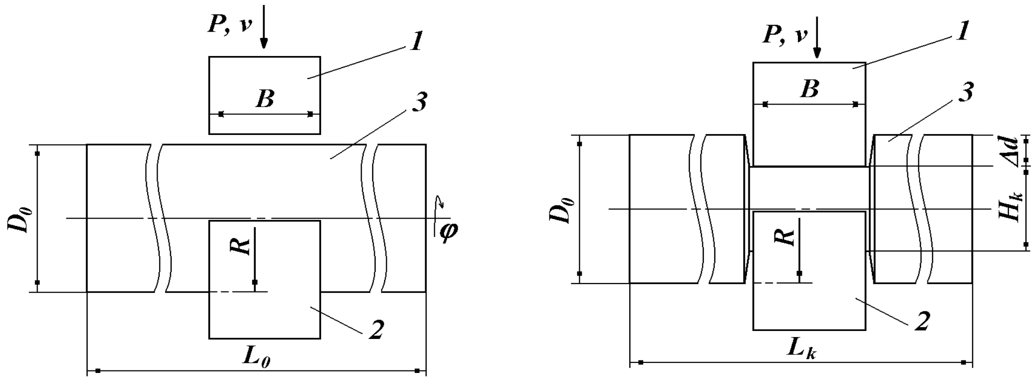
The samples were divided into two groups to study the effect of influence of stretch forging modes on the controlled indicators, each of which was assigned rotation angle $\Delta\varphi$, amount of reduction Δd and quantity of compression n till to full rotation of the work-piece to 360°. In the first group of samples ("0", "1", "2") varying of the rotation angle $\Delta\varphi$ was performed at a fixed value of compression Δd = 5 mm: a sample "0" – $\Delta\varphi$ = 30°, n = 12; a sample "1" – $\Delta\varphi$ = 60°, n = 6; a sample "2" – $\Delta\varphi$ = 90°, n = 4. In the second group of samples ("3", "5", "8") varying with the magnitude of compression Δd was performed at a fixed tilting of rotation angle $\Delta\varphi$ = 60°: a sample "3" – Δd = 5 mm, n = 6; a sample "5" – Δd = 6.6 mm, n = 6; a sample "8" – Δd = 9 mm, n = 6. Thus, the study was carried out at relative reduction: $\varepsilon_d = \Delta d / D_0$ = 0,1; 0,132 and 0,18.

In the experiments deformation force (P) was recorded on each swaging carried out for a given mode.



a b

Fig. 2 – Stamp block (a) for research of stretch forging of billets (b):
1, 2 – the lower and upper plates; 3, 4 – the upper flat and lower cut-out dies;
5 – fasteners, 6 and 7 – guides and springs, 8 – sample; 9 – testing machine



a b

Fig. 3 – Scheme of stretch forging of a billet:
a – before compression, b – after compressions with rotation of the work piece;
1, 2 – the upper flat and lower cut-out dies;
3 – billet; *P* and *v* – force of compression and speed of the tool

After each compression the length L_k of the deformed sample was measured (see fig. 3) and calculated its relative stretch by the formulas:

$$\lambda^{(I)} = \frac{L_k - L_{0y}}{B_m}, \quad \lambda^{(II)} = \frac{L_k - L_{0y}}{L_{0y}}. \tag{1}$$

After the last compression at full running-in for 360° an indication of relative stretch λ_k, hoods corresponding to the compression mode was got.

The forging of the work-piece at stretch forging is estimated with a parameter [1]:

$$У = F_0 / F_k, \tag{2}$$

where $F_0 = \pi D_0^2 / 4$ = 1962,5 mm^2 – the area of the cross-section of an initial sample;

F_k – cross-sectional area of the sample after reduction.

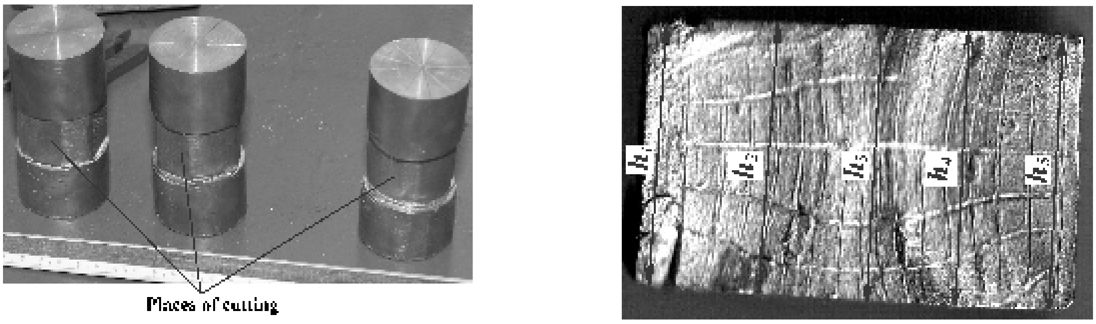
In these cases F_k can be determined in several methods.

The calculation method. It is calculated by the formula:

$$F_k^{(p)} = F_0 / \left(1 + \lambda_k^{(I)}\right). \tag{3}$$

The experimental and computational method. The method, which consists of cutting out of the middle portion of the deformed samples (see fig. 4, a) of templates, data weighting clippings to determine their mass

M_{Te} and measuring their heights $h_1, h_2, ..., h_5$ at different sites (see fig. 4, b) was developed to determine the geometrical characteristics of the deformed work piece.



a **b**

Fig. 4 – The samples after deformation:
a – the places of cutting out of templates in the samples «0», «1», «2»;
b – cut-out templates and heights measuring

Then the area of the deformed sample in a place of compression:

$$F_k^{(ep)} = V_{Te} / h_{cp}\,, \tag{4}$$

where $V_{Te} = M_{Te} / \rho_c$ – is the volume of cut out templates, here ρ_c = 11760 kg/m^3 = 11,76 · 10^{-6} kg/mm^3 – is the density of lead used;

$h_{cp} = (h_1 + h_2 + ... + h_5)/5$ – is an average height of the templates.

The experimental method with computer processing of images. Cut out templates were scanned and recognized using computer technology. To carry out the calibration the scanning was performed in conjunction with a reference element of graph paper (fig. 5). As the result the cross sectional area $F_k^{(e)}$ and the perimeter $\Pi_k^{(e)}$ of clippings from the experimental samples were defined.

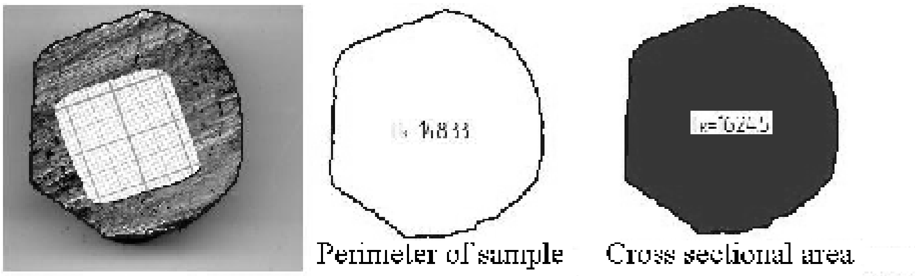


Fig. 5 – The example of the scanning of the templates for sample «3»
and determining of its geometric characteristics

Calculations revealed that the values of the areas, defined by the expressions (3) and (4) have a difference of not more than 2 %. This allowed further with a minimum error for the calculations only use data on the geometric characteristics of the cross-sections obtained by experimental design method.

As the perfectly round shaped figure is characterized by a minimum cross-sectional area ratio to the perimeter, the degree of approximation of cross-sectional shape of the deformed sample to the circle can be estimated with coefficients:

$$k_{\Pi} = \frac{\Pi_k^{(e)}}{\Pi_k^{(ep)}}\,, \quad k_F = \frac{F_k^{(e)}}{F_k^{(ep)}}\,, \tag{5}$$

where $\Pi_k^{(ep)} = \pi \cdot D_k^{(ep)}$ – is a shown (idealized) perimeter, here we have $D_k^{(ep)} = 1{,}13\sqrt{F^{(e)}}$ – is a shown cross-sectional diameter.

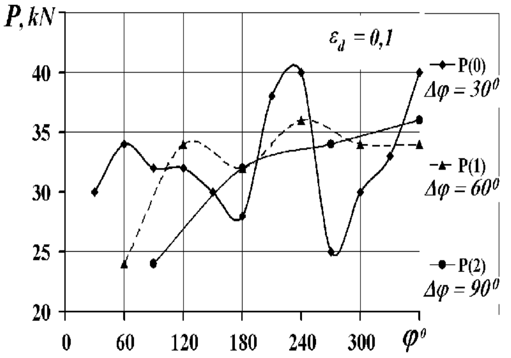
The closer the ratio (5) to the unit, the more regular geometrical shape is obtained in cross-section. In addition, experimental and calculated ratio of the area to the perimeter of the cross-section of deformed samples was computed:

$$k_e = F_k^{(e)} / \Pi_k^{(e)}\,, \quad k_p = F_k^{(ep)} / \Pi_k^{(ep)}\,. \tag{6}$$

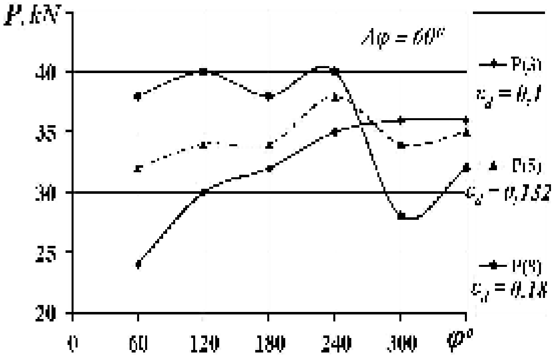
In order to fulfill the statistical processing of the results of the experiment the number of samples was increased to 5 for each tested mode of stretch forging.

Results of the research

The experimental distribution of forces on the reduction at various modes of stretch forging is shown on fig. 6.



a

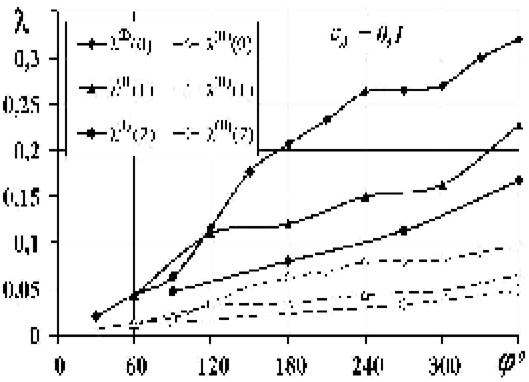


b

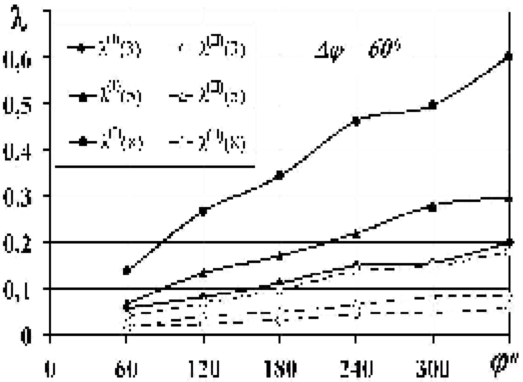
Fig. 6 – Experimental data on the distribution of reduction power at different modes of stretch forging with rotation of billets in combined dies:
a – for the samples "0", "1", "2";
b – for the samples "3 ", "5", "8"

Deformation modes, performed under the same reduction, but with different angles of rotation, are characterized by minimal power costs at the initial stages and the overall increase in the cost of power at the final stages of the rotation in diameter at stretch forging (see fig. 6, a). The greatest differences of power at reduction at various stages of running (at different total angle of rotation φ) are observed for samples, deformed at the lowest angles of rotation. Deformation modes, performed at the same angles of rotation, but with different reduction, are characterized by a general increase of the deformation forces during running around a diameter up to a total rotation angle φ = 240°. Further power costs are lower.

Fig. 7 shows a graphic plot of the relative stretch forging samples against different modes of stretch forging in rotation around the diameter at all stages of reduction. It is obviously that the relative stretching increases with the increase of the total rotation angle of the work piece. At deformation modes with a constant reduction and maximum angle of rotation ($\Delta\varphi$ = 90°, ε_d = 0,1, for the sample «2») minimum intensity of the stretching is observed (fig. 7, a). The maximum intensity of stretching for sample "8" is fixed, so at modes of deformation at $\Delta\varphi$ = 60° and maximum reduction ε_d = 0,18 (fig. 7, b).



a



b

Fig. 7 – Results of an experiment, investigating the relative stretching of a billet at various modes of stretch forging with rotation in combined dies:
a – for the samples "0", "1", "2";
b – for the samples "3", "5", "8"

Fig. 8 shows the results of studying of forging of the samples at different modes of stretch forging with rotation in combined dies. The forgings were determined for the final stage of running with a total angle of rotation φ = 360°. Increasing of the value of reduction leads to a increasing of the total forging, while the increasing of the angle of rotation affects badly on the intensity of the work-piece forging.

Results of studies of geometric characteristics of cross-sections of the samples, calculated by the expressions (5) and (6) after stretch forging in various modes are shown in the table 1 and in fig. 9. It is obviously, for the best results in terms of approximation of the cross-sectional work-piece to a shape of a circle is necessary to implement small relative reduction ($\varepsilon_d \cong 0{,}1$) with angles of rotation кантовки $\Delta\varphi$ = 60 … 90° with alternating the angles of rotation after a full turn of the work-piece to φ = 360°.

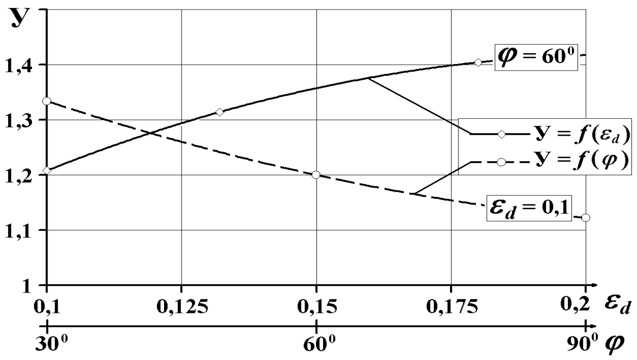


Fig. 8 – Forging of the samples at different modes in of stretch forging in combined dies

Table 1

The ratio of the area to the perimeter of the cross-sectional deformed samples at stretch forging in combined dies

Marking of a sample	Mode $\varepsilon_d \times \Delta\varphi$	k_e	k_p	$\delta_k = \dfrac{k_e - k_p}{k_e} \cdot 100\ \%$
«0»	0,1×30°	10,8	10,83	- 7,44 %
«1»	0,1×60°	11,04	11,26	- 1,72 %
«2»	0,1×90°	11,4	11,68	- 2,45 %
«3»	0,1×60°	10,97	11,25	- 2,55 %
«5»	0,132×60°	9,51	10,33	- 7,93 %
«8»	0,18×60°	10,127	10,53	- 3,95 %

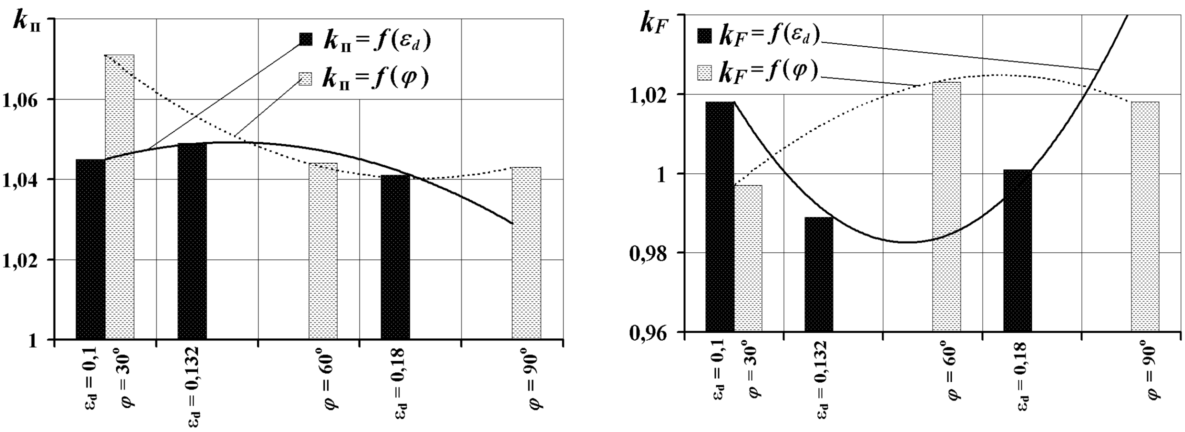


Fig. 9 – Results of investigation of geometrical characteristics of cross-sectional samples at different modes of reduction in combined dies

Minimum error for the sample is revealed for a sample "1" (ε_d = 0,1, $\Delta\varphi$ = 60, see the table 1), what confirms the conclusion that has just been done.

Conclusions

The technique of experimental studies of form changing and power mode of stretch forging of a billet with rolling in combined anvils was designed and implemented, based on the results of analysis of requirements for forgings shafts. The method of forging determining on the basis of experimental counted determination of the values of the finishing area of cross-sectional forging relative to the forging stretching, in height of cut out template and computer processing of scanned images of cutting out from the deformed part of the work piece, applicably to the processes of pulling of billets in combined anvils was further developed. The laws of change of power parameters and geometric characteristics of work pieces at stretching with rolling in combined anvils with different values of reduction and angles of rotation of work pieces around the longitudinal axis were adjusted. The conclusion was made, requiring a perspective study by checking the internal layers of the work piece, optimal modes of stretch forging with rolling in combined anvils from the point of view of achievement the best geometric characteristics of the cross-section of the forging. In according to method for produced of forging parts with shapes of cross-sections most neared to round pressing during stretch forging conducted to degrees of deformation in diapason 5 … 12 % with rotation after every stretch mode by angle 80 … 90°. Largest angle of rotation of rod billet securing for slender upsetting degree and for relative giving steps from 0,5 to 0,7.

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Кухар В.В., Василевський О.В. **Фізичне моделювання технологічних характеристик при ковальському протягуванні заготовок з обкаткою у комбінованих бойках.**

Обгрунтовано спосіб інтенсифікації деформування заготовок або злитків для досягнення ефекту макрозсувних деформацій при ковальському протягуванні у комбінованих бойках. Експериментальний аналіз формозміни заготовок при різних режимах гарячого протягування виконано на фізичних моделях зі свинцю. Пристосовано до нових умов ковальського протягування заготовок на гідравлічному пресі розвинутий метод експериментального дослідження технологічних характеристик при куванні. Визначено найкращі технологічні режими, такі як величина обтиску та кут повороту заготовки навкруг поздовжньої осі, для наближення поперечного перерізу заготовки до круглої форми та для отримання ресурсозберігаючого ефекту.

Ключові слова: ковальське протягування, комбіновані бойки, заготовка, фізична модель, формозміна.