UDC 621.73
DOI: 10.15587/1729-4061.2016.72063

DEVELOPMENT OF ALTERNATIVE TECHNOLOGY OF DUAL FORMING OF PROFILED WORKPIECE OBTAINED BY BUCKLING

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Показана можливість використання поздовжнього вигину як економічного способу безрівчакового профілювання заготовок. Для реалізації даного способу запропонована технологія спареного штампування поковок рим-болтів і розроблена компоновка штампового інструменту. Виконане дослідне штампування поковок рим-болтів по базовій і новій технологіях на свинцевих фізичних моделях заготовок. Порівняння результатів штампування поковки по двох варіантах виявило підвищення техніко-економічних показників нової технології

Ключові слова: спарене штампування, безрівчакове профілювання, профільована заготовка, поковка, рим-болт, поздовжнє згинання, викривлення торців, облой

Показана возможность использования продольного изгиба в качестве экономичного способа безручьевого профилирования заготовок. Для реализации данного способа предложена технология спаренной штамповки поковок рым-болтов и разработана компоновка штампового инструмента. Выполнена опытная штамповка поковок рым-болтов по базовой и новой технологиям на свинцовых физических моделях заготовок. Сравнение результатов штамповки поковки по двум вариантам выявило повышение технико-экономических показателей новой технологии

Ключевые слова: спаренная штамповка, безручьевое профилирование, профилированная заготовка, поковка, рым-болт, продольный изгиб, искажение торцов, облой

1. Introduction

Twin or multiple hot die-forging is applied at large-scale manufacturing of forgings with the objective of reducing metal consumption per a unit of production. Cases of application of twin forging for small-scale production are rather limited because of inevitable growth of expenses for costly forging tools and the necessity of application of more powerful equipment. Preliminary profiling of workpieces at die forging allows reducing of energy-power expenses and improving of dies durability, still for the greater part of forgings, manufactured in small scale rational profiling operations are missing.

Manufacturing of domestic forged eye-bolts is done in accordance with different processes, adapted to the equipment installed at the shop. Notwithstanding the well-known industrial standards (Inter-State standard GOST 4751 "Eye-bolts. Technical specifications", European standards ISO 3266, DIN 580, PN 82472, DIN 444, IS 4190 Indian standard) there are some data regarding various designs of parts of "eye-bolt" type, it being determined according to their type of manufacturing, designation and exploitation conditions. Eye-bolts can be different in shape and dimensions and they are classified according to the diameter of the ring-part, dimensions of their threaded parts and also by a type of their fixation, their toughness is also designated. For manufacturing of small and medium batches of eye-bolts of different design, preliminary profiling at forming steps is not executed, thus eliminating application of intricate tools and it often leads to an undesirable macrostructure of forgings with cutting of fibers and increased power and materials consumption. That is why development of a rational operation of profiling for manufacturing load bearing "eye-bolt" forgings is a vital task for improving of technical and economic indices of their small-scale manufacturing.

2. Analysis of literary sources and the problem setting

"Eye-bolt" part operates in strain and shear and bending strain originates in the circular area, while the treaded part experiences shearing stress. When the part is screwed into a handling appliance with a lever, inserted into the ring, it works it experiences torsion.

Dimensions of eye-bolts are chosen with due regard to references data [1, 2], depending on the type of rigging works, executed, and the mass of the load, the fixing scheme and the loading values. Their carrying capacity varies in a wide scale (40 kg to 20 T) and depends on location of the eye (its inclination angle) with respect to the stud of the appliance. Usually eye-bolt forgings are manufactured of carbon structural steel grades 20, 25 or 45, according to GOST 1050, application of alloyed steels is permitted.

Eye-bolts to be exploited under conditions of increased humidity (at sea-ports, on sea-going vessels etc.) undergo galvanizing [3]. It was found at investigating the destruction conditions of a galvanized part, supporting high-voltage wire that beside unfavorable external factors (great alternating loads experienced, corrosion) substantial influence on failure had been exerted by the substandard structure of used rolled steel [3]. It is evident that in order to improve macro- and micro-structure of steel parts die-forging with the formation of the required direction of fiber at preliminary profiling operations should be performed.

In the source [4], the ways of eye-bolts manufacturing in field conditions were listed, including forge welding of parts' elements. These methods are specified only for manual forging of eye-bolts in agriculture, their application is not recommended by industrial standards as their strength, and hence, personnel safety cannot be guaranteed.

Manufacturing of forgings in open dollies (dies) is done on forging hammers (FH), crank hot presses (CHP), hydraulic presses (HP) and screw friction presses (SFP). Their application is justified for full-scale or small-scale production of forgings. In source [5], a dolly was described for manufacturing of forgings, having relatively simple shapes in one pass. Investigations, performed with application of finite-element simulation method helped to reveal unfavourable thermal-cyclic loads, leading to destruction of stamps. For manufacturing of forgings with more intricate configurations, application of preliminary profiling or workpieces, manufactured in dolly-stamps is required [6, 7]. Their tools include replaceable rings, plates and for high-alloyed steels or non-ferrous alloys ensuring of the specified thermal forging mode acquires paramount importance.

It is known that sometimes prior to preliminary and final stamping such forging operations like flatting, broaching or fullering may be used [8]. Implementation of the process with a greater number of parts is accompanied by an increase in the width of the forging space that leads to application of power consuming equipment of higher capacity. Each separate pass for a group of forgings requires multiple heating of metal and leads to greater metal wastes due to burning-off, such wastes cannot be utilized. For manufacturing of eye-bolts in stamps of horizontal forging machines (HFM), it is necessary to ensure a series of thickenings in heading die impressions, forming, broaching and in some cases bending of the "eye" (a special part's shape) by the motion of a side slide-block. Intricate and metal consuming stamps and also peculiarities of the kinematics of HFM operation justify their application only for mass or large-scale manufacturing.

Group or multiple stamping is implemented with the objective of increasing coefficients of material application, as the process metal losses are distributed between several parts, forge from one and the same workpiece [9]. At multiple die-forging of small forgings, they are placed in a chain, 4 to 10 parts, one after another. Application of a standard insertion makes it possible to arrange on it two lines of figures with final shapes. After the figures of the first line have become worn out it will be possible to pass to forgings, placed on the second line.

Twin die-forging (dual forming) is a type of multiple stamping, cases of successful twin workpieces application for electric-hydraulic [10] and sheet [11, 12] forging are known. The objective of twin forging can also be improvement of the indices of application of workpieces metal [13]. For hot die-forging from twin workpieces, the design of preliminary die impressions is done with regard to the rational position of forgings on die bed, depending on the configuration of a workpiece, or semi-finished product [14, 15]. Application of these principles allows choosing the variant of forging from a workpiece of simple shape or with preliminary profiling. Efficient numerical or engineering methods are applied for design. Die-forgings in a twin workpiece are placed parallel, one after the other or at an angle to each other [16, 17]. Die-forging of workpieces with bent axes is done with preliminary profiling (on forging rolls [17]) or they are arranged symmetrically for a possibility to use workpieces of simpler shape. The performed investigation shows that the process of twin die-forging with a straight axis from preliminarily bent and profiled workpieces has not considered earlier. Hence, in order to improve the process of manufacturing of forged eye-bolts, it is required to apply economical profiling operations prior to the final stamping. Such operations must be performed on the main forging equipment without any increase in power and material capacity of forged parts. As such profiling operations, application of die impression-free processes of workpieces preparation, the concept of their utilization is described in [18] seems to be beneficial. On the basis of the principle of the maximum of free surfaces at die impression free profiling, technological processes of forging of round-shaped forgings, made from workpiece parts, profiled by means of upsetting with flat plates [19] and manufacturing of parts with edged tips, by the method of longitudinal rupture of the workpiece into two forgings were proposed [20].

In order to achieve resource economy, it is possible to reconsider the technological decision and shift from manufacturing single forgings for one stroke of the pressing machine to twin or multiple forging. Such combination of technological methods of impression-free profiling and twin forging is to allow to reach some positive results in essential improvement of efficiency of materials application. In the work indicated [12], optimizing algorithms are described, adapted to CAE-system, that can help specify the forging type and evaluate the workpiece's type for twin forging from a strip. Such analysis has been successfully implemented for achieving of material saving and improvement of the quality of parts, made of uniform or round-shaped billets [21, 22]. Application of impression-free technologies requires more accurate parameters, determining the field of the use of profiling operations. To such parameters belong not only characteristics of metal structure, but also the indices of shape and dimensions of profiled workpiece parts, that can guarantee manufacturing of high-quality forgings, their values requiring specification for each impression-free operation and every type of forgings.

A new process decision, comprising preliminary impression-free profiling of a relatively high workpiece (specified for two forgings), by longitudinal bending (buckling) with subsequent forging in a twin die was proposed. Buckling has always been considered as to be a negative phenomenon in forging technology, which has to be eliminated at preliminary upsetting of workpieces, so at the process of forging the conditions, preventing the formation of a defect of "suppression" in forging has to be ensured [23]. Buckling combines per one stroke of the press three technological processes: scale removal, bending and redistribution of metal, close to the configuration of the die impression.

Thus, the problem of designing a new process of manufacturing of forgings of "eye-bolt" type with the objective of improving of the coefficient of metal application is a very promising one. Adaptation of the process of small-scale die-forging to the existing facilities on the basis impression-free buckling of workpieces, excluding installation of more powerful or additional profiling equipment in the shop is of both practical and scientific interest. Evaluation of the efficiency of the new technology requires engineering analysis, analysis of geometrical indices, performing some design work and experimental forging of parts with comparison of technical and economic indices of forging precision by both variants (old and new), previously it was not done.

3. The objective of the work and the tasks for the research

The objective of this work is developing of the process of forming of "eye-bolt" type forgings with preliminary profiling, carried out on main forging equipment in order to improve technical and economic indices of the manufactured products.

The following tasks were set for reaching the objective desired:

– to carry out the engineering analysis of forging-part and to select an economical method of obtaining profiled workpieces and forming of eye-bolts forgings;

– to analyze shape formation of the butt sections and develop the methods of evaluation of their distortion at profiling by means of longitudinal bending for estimation of the value of contortion at the stage of designing the processes of forging and stamping production;

– to develop the design of forging and stamping tools and to carry out the test forming of eye-bolt forgings with application of new technical solutions;

– to compare technical and economic indices of the proposed and conventional processes.

4. Material of research: equipment, tools, technological analysis and justification of pre-profiling of a workpiece by buckling for dual forming of "eye-bolts"

The process was developed for eye-bolt forgings, stamped in dolly-die on SFP with nominal force, equal to 6.3 MN. Construction of the epures of diameters (of a specified workpiece) and section epures was carried out in accordance with well-known rules [6, 10], i. e. for each particular i-th section its area $S_{p.i}$ was determined as well as the area of two-sided fin $2S_{ob}$ with due regard to stack filling. Then, the area of the epure in its *i*-th section $S_{e.i} = S_{p.i} + 2S_{ob}$, and the corresponding diameter is: $d_{e.i} = 1{,}13\sqrt{S_{e.i}}$. The epure of the diameters for a forging of "eye-bolt" type (Fig. 1, *a*), is pictured in Fig. 1, *b*. For obtaining of the epure of sections, a scale factor M= 20 was taken, the height of the section will be, then $h_{e.i} = S_{e.i} / M$. The sections epure is shown in Fig. 1, *c*. The sketch of the process die is shown in Fig. 2.

According to the base technology, forming is made from a workpiece the diameter of which should be not less than the maximal diameter of the epure $D_0 \geq D_{e.max}$. I. e. the workpiece's dimensions are: initial diameter D_0=30 mm (∅ 30 GOST 2590), initial height H_0=72 mm. When workpieces are cut from a unified bar of rolled stock 6000 mm in length, the rate of metal consumption, evaluated in accordance with recommendations [6], is K_r=0.98. The volume of the workpiece (without metal waste, other conditions being similar, and also with regard to the predicted physical modelling of the workpieces on lead billets, without heating): V_{zag}=50868 mm^3. The volume of the diameters volume per one forging: V_e=32948 mm^3. The mass of a steel workpiece (let us take steel's density as ρ=7860 kg/m^3): M_{zag}=0.4 kg. The rate of metal consumption [6, 18]: $N_r = M_{zag} / K_r$= =0.399/0.98=0.408 kg. Coefficient of production of quality forgings [11]: $K_v = M_p / M_{zag}$ =0.190/0.4=0.475. Coefficient of usage of forging's metal according to the consumption rate [11]: $K_{ip} = M_p / N_r$ =0.190/0.408=0.466. The volume of additional metal of the workpiece $V_{add}=V_{zag} - V_e$=50868–32948= =17920 mm^3. The mass of additional volume (extra consumption of metal) of the workpiece: M_{add}=0.141 kg.

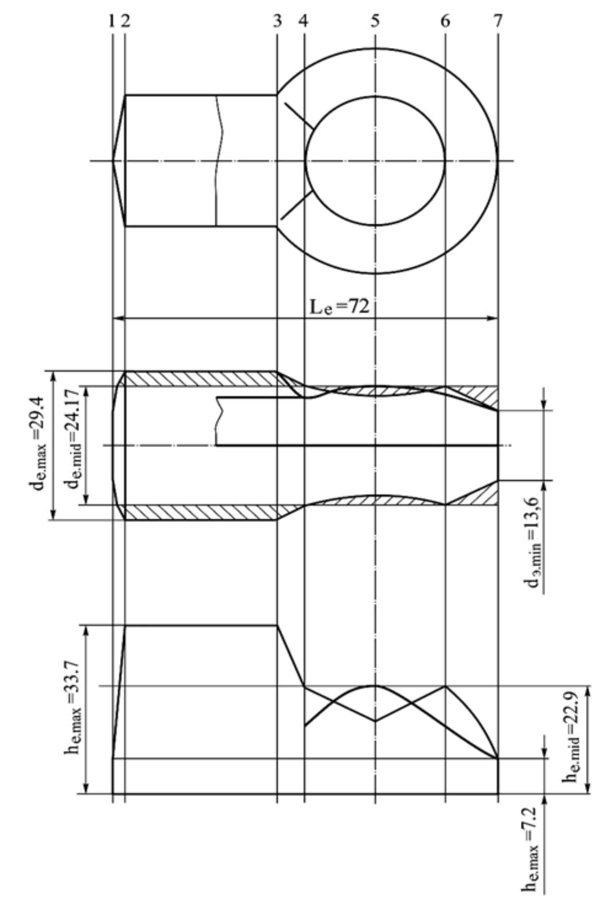

Fig. 1. The engineering analysis of "eye-bolt" forging: *a* — sketch of a forging-part; *b* — diagram of diameters; *c* — diagram of cross-sections

With the objective of improving the technical and economic indices, a technical solution was proposed, that included preliminary impression-free profiling of a relatively high workpiece (for two forgings) by buckling with subsequent die-forging in dual dies. As a result of buckling, the workpiece is bent with redistribution of metal at which the bulge in the central part is formed. Broaching of a profiled workpiece for dual forming of forgings of eye-bolt type corresponds mostly to the epure of diameters of dual forging (Fig. 3).

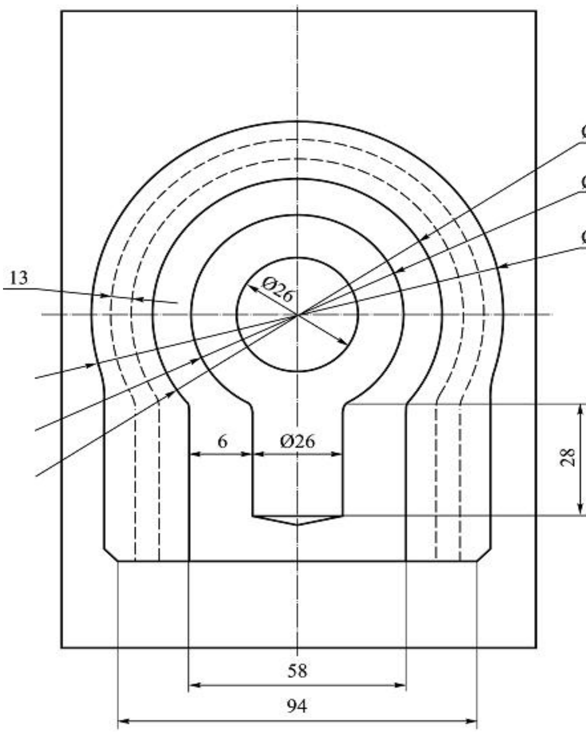

Fig. 2. A sketch of the die cavity for forming of eye-bolts

Broaching length and the volume of a specified workpiece (of an epure of diameters for a double forging with flash) for dual forming L_{e2}=144 mm and $2V_e$=65,896 mm^2. The average area of the epure is: $S_{e.mid}=2V_e/L_{e2}$=65896/144=457.6 mm^2. The average and maximal diameters of the epure are: $D_{e.mid}$= =24.17 mm and $D_{e.max}$=29 mm. A. V. Rebelskiy's criteria [6] were evaluated for this forging, characterizing its complexity: α=1.22 and β=2.97; so, according to the determining diagram (the source [6], for instance) manufacturing of this forging requires application of a broaching (or a pinching) impression. Edging coefficient being [6]: $K_{po}=(D_{e.max}/D_{e.mid})^2$=1.49. It is impossible, however, to reach the edging coefficient $_{po}$ on pressing equipment excluding application of edging or pinching impressions. The diameters of epures obtained and the edging coefficient K_{po} correspond to a basic example of forming of a single forging from a single workpiece, thus confirming the necessity of profiling.

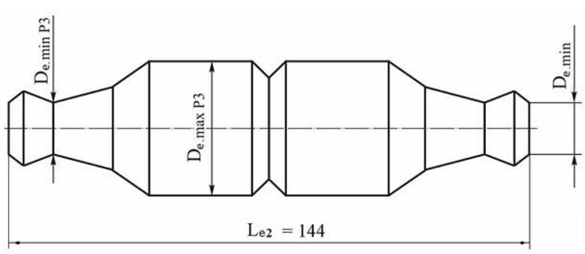

Fig. 3. The sketch of the shape of broaching of a specified workpiece for dual forming of two forgings of "eye-bolt"

Common method of physical modeling of hot deformation processes on the lead workpieces was used for the experimental forging in the laboratory conditions. At the room temperature, in the lead take place processes that similar to recrystallization in the steel workpieces at high temperatures [24]. Flow curves of the lead and hot steel have similar characteristics, and addition of alloying elements (like antimony, zinc, etc.) to the lead allows to select the compounds that physically simulate the deformation of certain steel grades [25]. The use of lead as a modeling material is well-founded and much extended.

5. Development of methods for accounting of distortion of workpiece butts during profiling to forgings

With application of the method of experimental planning, regression dependencies of geometrical characteristics of butts distortion were obtained in relation to the original height (L_0) to the diameter (D_0) of the workpiece and conventional degree of upsetting $\varepsilon_y=(L_0-H_k)/L_0$ (where H_k is the final height of the workpiece). The overall view of the polynomial, describing regression dependencies of the criteria of shape alternation upon the factors of influence at buckling of a workpiece, round in cross section:

$$Y=b_0+b_1X_1+b_2X_2+b_{12}X_1X_2, \quad (1)$$

where Y is controlled criteria forming a, b and c (Fig. 4); $X_2=(\varepsilon_y-0.34)/0.2$ is a coded value of the factor, characterizing the influence of a conventional degree of deformation at longitudinal bending (buckling).

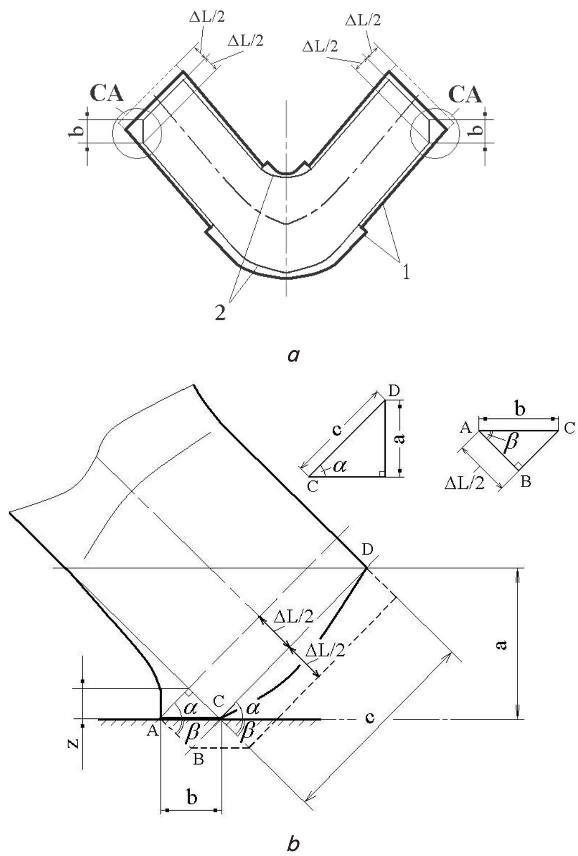

Fig. 4. On evaluation of distortion of the butts of the workpiece, profiled by buckling at further stamping: *a* — position of the forging in the stamp's die bed contour; *b* — diagram for evaluation of the data increase of the length of broaching of the profiled workpiece; 1 — impression's shape; 2 — the shape of the workpiece

For workpieces with bigger cross section, the coded values of the factor of relative height within m_0=4.0...5.0 and m_0=5.0...6.0 intervals are $X_1 = (m_0 - 4.5)/0.5$ and $X_1 = (m_0 - 5.5)/0.5$ respectively.

As a result of investigations performed and corresponding evaluations, quantitative values of equations coefficients (5) were obtained for different criteria of forming Y, they are represented in Table 1.

Table 1

The values of coefficients of the regression equation (1) for evaluation of the criteria of forming of workpieces of round cross section

Y	b_0	b_1	b_2	b_{12}	Y	b_0	b_1	b_2	b_{12}
m_0=4.0–5.0					m_0=5.0–6.0				
$(a/D_0)\cdot 100$	25.53	16.03	19.93	11.43	$(a/D_0)\cdot 100$	54.9	13.35	34.2	2.85
$(b/D_0)\cdot 100$	70.63	−14.9	−2.13	−7.63	$(b/D_0)\cdot 100$	43.98	−11.8	−7.32	2.43
$(c/D_0)\cdot 100$	54.08	23.07	18.58	4.57	$(c/D_0)\cdot 100$	85.95	8.8	19.2	−3.95

The data of the regression equation were used for solution of two main problems:

Problem 1 – evaluation of butts distortion at subsequent forming of a profiled workpiece inside the stamping impression, in which distorted butt sections are placed into the side elements or tag cavities of the die impression contour.

Problem 2 – evaluation of butts distortion at manufacturing of the parts with a bent axis, when after buckling the butt sections do not undergo plastic deformations.

Let us explain our selection of problems:

Problem 1. The greater m_0 relation at longitudinal bending of workpieces the bigger is the butt's surface that is detached from the plane of the upsetting plate and, hence, lesser distortion of the butt sections could be observed. At further forging of a profiled workpiece inside the impression for manufacturing of bent workpieces, where distorted butt sections are placed in the extreme elements or in tags cavities of the die bed contour it is required to examine the filling of those cavities with metal. Such examination, when a new process is implemented, can be performed by test forming, if it is possible to take a complete consideration the deformation conditions by a finite-element simulation of metal flow. Let us note here, that these measures increase the total material consumption of production and also labour consumption at the design stage and that is why they require developing of an alternative engineering method.

Problem 2. At manufacturing of parts with a bent axis, when after buckling the butt sections do not undergo plastic deformation it is necessary to compare the distortion dimensions with dimensions of maximum permissible deviations or positive allowances for subsequent mechanical treatment of the part.

Problem 1. Let us consider the variant with placement of a bent profiled workpiece inside the die bed contour of a stamp for manufacturing of forgings with bent axes (Fig. 4, *a*). At distortion of the butt section at the value equal to *b* it is required to enlarge the length of the tags of the profiled workpieces, i.e. enlarge the broaching length of the profiled workpiece by ΔL (Fig. 4, *b*) for filling of cavity angles (CA) (Fig. 4, *a*). The analyzed of distortion was caused by shifting of a volume part, the total value of the metal volume at the tag section being intact. The metal protruding outside the die impression contour limits is pushed into flash at the next stamping step.

From *ABC* triangle (Fig. 4, *b*) we find that $\Delta L/2 = b\cdot\cos\beta$, at that the angle $\beta = (90^{\circ} - \alpha)$. Judging by geometrical relationship in Fig. 4, *a–c*, evidently, are easily found [27]: $\alpha = \arcsin(a/c)$.

Then, in the long run, we'll have:

$$\Delta L = 2\cdot b\cdot\cos\left[90^{\circ} - \arcsin\left(\frac{a}{c}\right)\right]. \quad (2)$$

With the length of the epure of diameters known (L_e), the corrected shortening of the workpiece's axis (δ), profiled by buckling is:

$$\delta = 1 - \frac{L_e + \Delta L}{L_0} = \frac{L_k + \Delta L}{L_0}. \quad (3)$$

Taking into account that

$$D_0 = 1{,}08\cdot\sqrt[3]{(V_e + \Delta V_e)/m_0},$$

where and ΔV_e are the volume of the diameters epure and additional volume, due to the length increment of the profiled workpiece by ΔL, we can represent the equation (3) in the following view:

$$\delta = 1 - 0{,}926\frac{L_e + \Delta L}{m_0\cdot\sqrt[3]{\dfrac{V_e + \Delta V_e}{m_0}}}. \quad (4)$$

There $(L_e + \Delta L) = L_e(1 + \Delta L/L_e)$, and also $(V_e + \Delta V_e) = V_e(1 + \Delta V_e/V_e) = V_e(1 + \Delta L/L_e)$.

Now, let us evaluate the initial rated value of the relation $m_{0.0}$, at which for the specified V_e and L_e the value of $\delta=0$. Then, after rearranging we shall have from the expression (4):

$$m_{0.0} = 0.891\left(1 + \frac{\Delta L}{L_e}\right)\sqrt{\frac{L_e^3}{V_e}}. \quad (5)$$

Or, taking into account that $L_e = L_0(1-\delta)$, at $\delta=0$ we can write:

$$m_{0.0} = 0.891\left(1 + \frac{\Delta L}{L_0}\right)\sqrt{\frac{L_e^3}{V_e}}. \quad (6)$$

Then, applying the equation (2), we can write the corrected expression for evaluation of a relative height of a workpiece with a cylindrical shape:

$$m_0^{*} > 0.891\left(1 + \frac{2\cdot b\cdot\cos\left[90^{\circ} - \arcsin\left(\dfrac{a}{c}\right)\right]}{m_0\cdot D_0}\right)\sqrt{\frac{L_e^3}{V_e}}. \quad (7)$$

As the parameters $a = a(m_0;\varepsilon_y)$, $b = b(m_0;\varepsilon_y)$ and $c = c(m_0;\varepsilon_y)$ are functions, determined by the regression equations (1), the expression (7) is then a transcendental inequality. From an engineering point of view, the indicated functions as m_0 represent the value, calculated by means of (5) equation.

Problem 2. Let us analyze the variant when a profiled workpiece does not undergo any further plastic deformation in the vicinity of the butts. In this case the value of distortion b should not exceed the sum of hypotenuses of NMG and MKF triangles (Fig. 5), where legs are positive tolerances for mechanical treatment (and/or the values of permissible deviations): $T_p/2$ is an unilateral positive tolerance (allowance), T_p^f – the finishing positive tolerance (allowance). Let us write down:

$$b \le (x_1 + x_2). \quad (8)$$

We'll evaluate one-sided distortion like that:

$$p = b \cdot \cos\alpha; \quad q = b \cdot \sin\alpha. \quad (9)$$

At that the angle α, like in the previous case: $\alpha = \arcsin(a/c)$.

The values x_1 and x_2 can be found in the form of relations (Fig. 5):

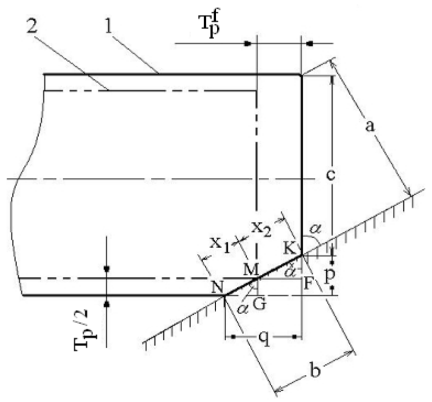

Fig. 5. On evaluation of distortion of the workpieces' butts at finishing operation of profiling by longitudinal bending: 1 — forging's contour; 2 — part's contour

$$x_1 = \frac{T_p/2}{\cos\alpha} \text{ and } x_2 = \frac{T_p^f}{\sin\alpha}. \quad (10)$$

Taking into account that $\cos\alpha = \sqrt{1-\sin^2\alpha}$, we can finally write down:

$$x_1 = \frac{T_p/2}{\sqrt{1-(a/c)^2}} \text{ and } x_2 = \frac{T_p^f}{(a/c)}. \quad (11)$$

Then, the condition (8) acquires the view:

$$b \le \left[\frac{T_p/2}{\sqrt{1-(a/c)^2}} + \frac{T_p^f}{(a/c)}\right]. \quad (12)$$

The T_p and T_p^f values are set by the corresponding standards, while the parameters $a = a(m_0;\varepsilon_y)$, $b = b(m_0;\varepsilon_y)$ and $c = c(m_0;\varepsilon_y)$ are calculated from regression equations (1).

6. Experimental application and discussion of the results of research of "eye-bolt" dual forming from the profiled workpiece obtained by buckling

The developed method was applied for evaluation of steps and workpiece's dimensions for dual forming of forgings of "eye-bolts" and also for implementation of the process of industrial manufacturing of forgings of "buckle" type at forging and pressing shop of "Ilyich" Iron and Steel Works PSC (Mariupol, Ukraine), now in structure of "Metinvest – Mariupol Mechanical Repair Plant" LLC. The values of the appropriate technical and economic indices are summarized in Table 2.

According to the principles of impression-free profiling of forgings by longitudinal bending, as the proposed process requires the cut workpiece is set with some loss of stability, the profiled semi-finished product is placed on its side and then it is put into the impression for forming of two forgings from one workpiece. For evaluation of the relation of m_0 length of the dual workpiece for two forgings (L_0) to the diameter (D_0) and the degree of specific deformation (ε_y) at longitudinal bending calculations, according to the equation (6) were first made. For the initial case ΔL=0 was taken, then, $m_{0.0}^*$=5.998, i. e. m_0>5.998. For arrangement of the stamp with two forgings placed at φ angle, we found from geometrical relations that $\varphi \ge 48°$ (Fig. 6). For evaluations, we understood that m_0=6.0. Then, according to the source [18], for this particular relation, the central angle is to acquire the desired value φ=48° at ε_y=40 %.

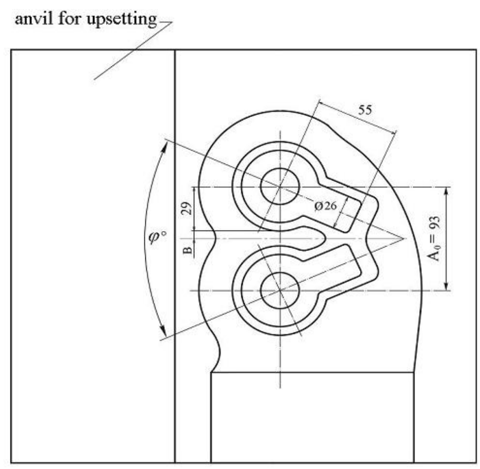

Fig. 6. The die design for dual forming of forgings of eye-bolts with profiling of workpieces by longitudinal bending

Macro-indices of shape alternation at specified technological parameters of profiling are [27, 28]: $K = D_{e.max}/D_{e.minRZ}$=1.126, $k_1 = D_{e.minRZ}/D_0$=1.041, $k_2 = D_{e.max}/D_0$=1.171. The workpiece's diameter was chosen with the regard to the condition of possibility of metal filling on the spot of the biggest diameter $D_{e.max}$. Preliminarily: $D_0^* = D_{e.max}/k_2$=29.4/1.171=25.1 mm. With some allowance we took D_0=26 mm (∅26 GOST 2590). In sections, corresponding the minimal diameter of the epure, the filling of metal is to exceed the desired value: $D_{e.minRZ} = k_1 \cdot D_0$=1.041×26=27.06 mm. Then, the rated minimal sufficient length of the initial workpiece should be: $L_0 = m_0 \cdot D_0^*$=6×25.1=150.6 mm. The rated volume of the epure of diameters (of the rated workpiece) for two forgings: V_{e2} =79.917 mm³.

At buckling of plastic workpieces, there is distortion of butt sections happens, it requires elongation of the workpiece. The value of ΔL was evaluated in accordance with the results obtained from [27, 28] source: ΔL=5.2 mm. From there (according to the formula indicated above):

$$m_{0.0} = 0.891\left(1+\frac{5.2}{144}\right)\sqrt{\frac{144^3}{79917}} = 5.643.$$

Finally, the length of the workpiece was taken as $L_0 = D_0 \cdot m_{0.0} + \Delta L$=152 mm. The corrected relation is: m_0=

$=152/26=5.85$. Consequently, observing the condition [27]: $(m_0=5.85)>(m_{0.0}=5.643)$. The required shortening of the axis of the workpiece $\delta=[(152-144)/152]\times 100\ \%=5.3\ \%$. The amended value: $\varepsilon_y=0.39$ (39 %). For the specified values of m_0 and ε_y the central angle $\varphi=54°>48°$. The ultimate height up to which the workpiece must be set at longitudinal bending: $H_к=L_0(1-\varepsilon_y)=152\ (1-0.39)=93$ mm.

For the variant of dual forming from bent workpieces, the die's design for which is represented in Fig. 6 the value of [6] was calculated: $K_r=0.994$. The volume of the workpiece for two forgings with the final dimensions was: $V_{zag2}=80660$ mm^3, i. e. per one forging $V_{zag1}=40330$ mm^3. The mass of a steel workpiece for two forgings is $M_{zag2}=$ $=0.634$ kg, for one forging $M_{zag1}=0.317$ kg. The consumption rate: $N_r=0.317/0.994=0.319$, and also $K_v=0.19/0.317=0.599$, $K_{ip}=0.19/0.319=0.596$. Additional (compensation) metal volume: $V_{add}=V_{zag}-V_e=40330-32948=7382$ mm^3. The mass of the additional volume (metal overcharge) of the workpiece: $M_{add}=0.058$ kg. The results of the comparison of the conventional and the new variants of stamping are summarized in Table 2.

Table 2

Comparison of technical and economic indices of the accuracy of forming of the basic and proposed variants

Index	Conventional process	The developed process	% percentage from the conventional process
K_r	0.98	0.994	101.4
K_v	0.475	0.599	121.1
K_{ip}	0.466	0.596	127.9
M_{zag}, kg	0.4	0.317	79.3
N_r, kg	0.408	0.319	78.2
M_{add}, kg	0.141	0.058	58.9

With the aim of confirming the advantages of the modified process, the comparison was made of the die-forging variants in dolly-dies according to the conventional (Fig. 7) and the new variant (Fig. 8). For evaluation of "forming ability" of "eye-bolt" according to the modified process, profiled semi-finished products (Fig. 8, *b*) were placed into the existing die after preliminary sawing-off along the cross-section (Fig. 8, *c*, *d*). In both cases, the die's bed contour was lubricated with industrial lube oil.

At forming according to the conventional process, much flash is observed within the ring-part area of an "eye-bolt". At forming of a profiled workpiece, the amount of flash formed is much less, than at the conventional variant (Fig. 9). Besides, more uniform distribution of flash along the forging's perimeter is observed, particularly, in the area of transition of the rod into the ring part the flash is minimal (Fig. 8, *e* and Fig. 9), due to the particulars of semi-product's shape.

Comparison of the volumes and masses of workpieces revealed that the proposed process allowed reaching metal saving, amounting to 21.7 %.

a

b

Fig. 7. Forming of forgings of eye-bolt type according to the conventional technology: *a* — workpiece (30 mm diameter, 72 mm length) in a die; *b* — a forging with flash in a die

a

b

c

d

e

f

Fig. 8. Forming of eye-bolt forgings according to the modified process: *a* — sequence of steps; *b* — initial workpiece, designated for two forgings (26 mm diameter, 152 mm length); *c* — profiled workpiece; *d* — the workpiece after separation; *e* — placement of the workpiece into a die; *f* — stamped forging with flash in a die

Fig. 9. Comparison of forgings with flash, the left one was profiled with buckling and the right one was manufactured according to the conventional technology

7. Conclusions

1. The methods of impression-free profiling, namely, buckling of workpieces for the processes of forming on Screw friction presses were developed. A possibility of application of buckling as an economical method of profiling of workpieces was shown, ensuring replacement of pinching and edging impressions before forming of forgings of "eye-bolt" type, the method of dual forming of such forgings having been developed.

2. On the basis of the experimental design theory, regression dependencies were obtained for evaluation of the criteria of shape alternation for workpieces of a big cross-section and distortion of butt sections, applicable for simulation and design of steps of forming the forgings of typical configuration and other multivariate problems.

Equations of linear regression with regard interaction of the factors concerned represent dependencies of geometrical characteristics of distortion on the butt ends at buckling of workpiece upon their original height to the diameter and conventional degree of upsetting.

The analysis of the data of regression models shows that the factor of conventional degree of upsetting is more essential, by 20...60 % , than the factor of relative height of the workpiece from the point of view of the influence on distortion of the butt (detachment of its part and ascension over the upsetting plate – (a/D_0)) parameter.

This fact should be especially borne in mind at the designing stage, when a profiled workpiece must be placed into the die impression. The length of the contact of a supporting part of the butt with the upsetting plate (b/D_0) is influenced mainly by a relative height of the workpiece, so, if it is necessary to observe the requirement for parallelism of the butts of the profiled workpiece, its relation of height to diameter should be chosen as little as possible. The influence of two input variables (m_0 and ε_y) upon the length of the elevated part of the workpiece's butt, which has no contact with the upsetting plate (c/D_0), is constant and depends upon the relative height of the workpiece. At m_0=4.0...5.0, this input variable exerts by 19 % greater influence upon the length of the elevated part of the workpiece's butt than the conventional degree of upsetting. At m_0=5.0...6.0, the conventional degree of upsetting is by 54 % more essential factor than the relative height of the workpiece. At the design stage of technological solutions, the fact that parts of workpiece's butts, which have no contact with upsetting plates are not flat should be taken into consideration.

3. A configuration of the die for the proposed process of manufacturing of forgings of eye-bolts was designed. It was found that profiled semi-finished products acquire the desired shape at the degree of upsetting of cylindrical workpiece equal to ε_y=39 %, in this case the central angle between the dual forgings will be 54°, it is taken into account for the die's design.

4. Experimental forming of eye-bolt forgings was carried out on lead physical models of workpieces, according to the conventional and proposed methods. It was revealed that the proposed process decision ensured metal saving up to 21.7 % level.

5. The comparison of the results of forming of forgings of "eye-bolt" type according to two variants revealed raising of technical and economic indices for the new process, particularly the coefficient of metal consumption at cutting was increased by 1.4 %, the coefficient of production of final forgings – by 21.1 %, the coefficient of application of metal of forging per consumption norm – by 27.9 %.

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