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IMPROVEMENT OF PROCESSES OF ROLLING STAMPING ON THE BASIS OF INVESTIGATION OF TECHNOLOGICAL PARAMETERS ON THE MECHANICS OF WORKPIECES' FORMATION

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Summary. The agrarian sector of Ukraine today is one of the main sectors of the economic complex, which provides the largest inflows to the budget of the country. This circumstance determines the priority of development of agro-industrial production. The development of the agrarian sector and the need to increase its efficiency require the improvement of the technical support of agrarian production. Ukraine has a powerful machine-building complex to meet the challenges of providing agricultural production with modern machines and equipment. At the same time, domestic industries of machine building and metalworking, which are designed to increase the competitiveness of their own products, are still largely based on energy and metal-intensive technological processes. The reduction of energy and material costs is facilitated by the development and introduction of new processes in the treatment of metals by pressure (PMT) in metal processing.

In this article the peculiarities of local deformation are analyzed, which determine the stamping by rolling as an independent type of metal treatment by pressure in the metalworking industry. Most effectively, this problem is solved by using cold plastic deformation processes, which allow as much as possible to bring the shape of the work piece to the shape of the finished product, and in some cases preclude the need for further processing. Using the method of cold deformation instead of cutting, it is possible to increase the coefficient of use of metal in 2-3 times. This ensures high quality of the surface of the work pieces, improves the physical and mechanical characteristics of the material, increases productivity and creates conditions for complete automation of production. The examples of the most complete realization of the advantages of stamping by rolling are provided, which ensures the efficiency of industrial use. In the priority directions of science and technology development a special role is assigned to energy and resource conservation. Modern domestic engineering and metalworking industries, which are designed to increase the competitiveness of their own products, are still largely based on energy and metal-consuming processes. In order to increase technical support, we need the development of the agricultural sector and its efficiency.

Key words: rolling stamping (RS), pressure metal treatment (PMT), cold forging.

INTRODUCTION

In machine building, rolling stamping (RS) is becoming more commonly used - a method of local plastic treatment under pressure, in which the deformation of the workpiece in the face and at different angles to the longitudinal axis occurs. The localization of the deformation zone and the increased stiffness of the equipment and tools allow us to use this method for processing in a cold state of metals, including steels and alloys of high strength, while ensuring high productivity, the level of resource conservation and the quality of the products obtained [1-4]. PMT processes extend the technological capabilities of low-waste production of high-quality products of complex shape. A special place among the processes of PMT take the methods of local deformation, in particular rolling stamping. The insignificant contact area of the tool with the workpiece causes relatively small forces of deformation, and favorable conditions of the flow of material in the contact zone contribute to the formation of developed tubular, cylindrical elements of preforms of complex shape. The versatility of the equipment and the relative ease of tools allow us to use the RS processes to produce a wide range of products. At the same time, the possibility of achieving large deformations is limited to the risk of destruction of the workpieces and loss of stability of their individual parts. An important task is also to ensure the possibility of producing preforms of a certain shape and size of high quality [2-3]. And the possibility of implementing a variety of deformation schemes make RS quite a promising direction of metal treatment by pressure.

Improvement of RS processes is constrained by the underdeveloped calculating apparatus of the formation mechanics, which is intended to provide: the determination of the kinematics of the flow of metals and the evaluation of the influence of the parameters of technological processes on it; determination of metal ductility; analysis of the stress-strain state and the accumulation of damage in the material of the workpieces; determination of influence of the value of the used plasticity resource on the service characteristics of the products [5-6].

For the solution of this problem a significant input can be made by modern technologies based on methods of treatment of metals by pressure [7]. In the choice of technological processes, equipment, tools and equipment, in addition to technical and economic efficiency, technologists and designers are increasingly interested in the technological capabilities of the processes and their power-supply parameters, which determine the power of the drive of the working mechanisms, overall dimensions, weight of equipment and other parameters [7-8].

ANALYSIS OF RESEARCHES AND PUBLICATIONS

The study of the deformability of metals is based on the methods of continuum mechanics, mathematical and applied theory of plasticity, phenomenological theory of deformability [8]. To investigate the processes of RS we use the following methods: theoretical (application of the apparatus of analytical geometry, tensor analysis, mathematical analysis) – for the development of mathematical models; experimental – calculation (dividing grids, hardness measurement, microstructural, X-ray diffraction) and numerical (finite element method) – for analysis of the stress-strain state of the workpieces [9-11].

OBJECTIVES

The methodological basis of the research is the position of mathematical theory of plasticity and mechanics of scattered destruction. To achieve the goal, the following research methods were used: theoretical (analytical geometry, mathematical analysis during the creation and research of mathematical models), experimental (construction of boundary deformation curves during stationary deformation, determination of stress-strain state by the method of coordinate grids, natural experiments under laboratory conditions), experimental-analytical (apparatus of mathematical statistics for the processing of experimental data, approximation of dependencies between component deformations), numerical simulation of deformation processes using complex software DEFORM - 3D [10].

THE MAIN RESULTS OF THE RESEARCH

The technological capabilities of the RS are limited, mainly, to the loss of stability and the destruction of the workpieces, which, in turn, is determined by the direction and intensity of the flow of metal in the workpiece in the contact area with the roll. Thus, the possibility of controlling the flow of metal in the workpiece at contact with the roll, is to a large extent determined by the possibility of manufacturing the workpieces of the required shape and dimensions without destroying and losing stability. In the experimental study of the kinematics of the material of the workpiece on contact with the roll, it was established that the direction of such a flow in the contact area depends on a number of parameters. The main of them is the magnitude and direction of the roll off δ with respect to the axis of the workpiece, as well as the angle of inclination of the roll α [12] α.
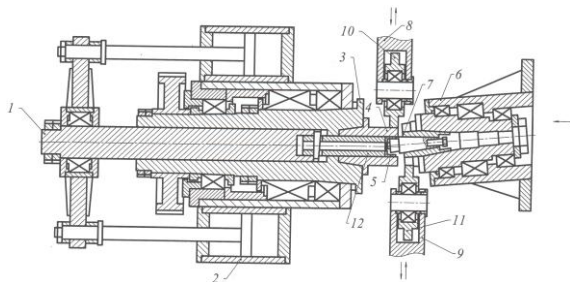

Fig. 1. Prefabrication for implementation of rolling stamping processes
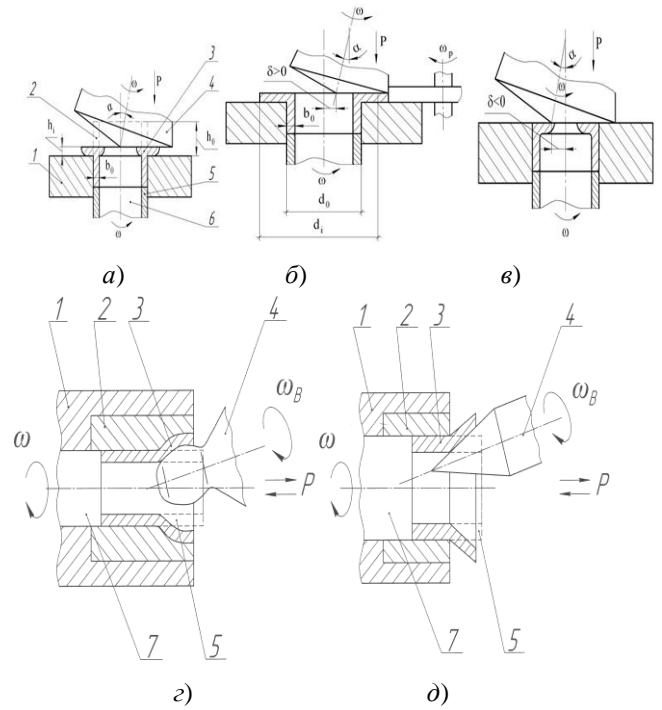

Fig. 2. Influence of the direction of displacement of the peak of the roll of the axis of the workpiece on the shape change of the workpiece during the loading of the clamps by the method of RS

In accordance with the calculations carried out in [14], with a negative displacement of the roll, material flows to the center of the workpiece, and at a positive - from the center.

The dependence of the angle Ψ between the projections of the straight lines, on which the vectors of the velocity of the roll and the workpiece lie on the plane, on the direction and magnitude of the displacement of the roll δ relative to the axis of the workpiece, at different angles of the roller cone, is shown in Fig. 3 [13].
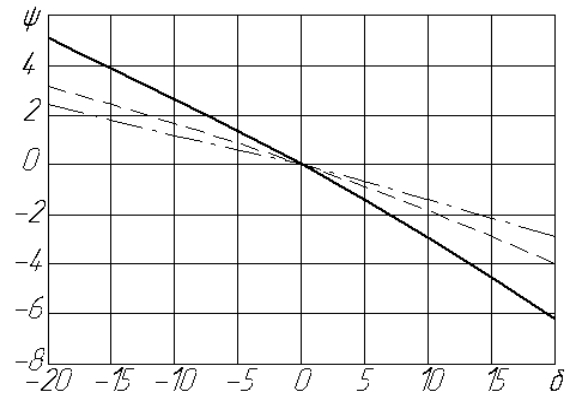

Fig. 3. Dependence of the angle Ψ from the direction and the displacement value δ at different angles of the cone: $\alpha = 2^{\circ}$ (solid line), $\alpha = 10^{\circ}$ (dashed line), $\alpha = 20^{\circ}$ (dashed-dotted line)

The obtained analytical dependencies provide a reference point for controlling the flow of metal in a given direction when the tubular blanks are rolled by the schemes of deposition, upsetting, screening, profiling, etc. [13].

A detailed study of the influence of all possible factors on the deformation process by rolling using experimental methods is quite labor-intensive. To the significant shortcomings of theoretical methods of research should include the complexity and even the impossibility of their application to address the noted problem in the RS processes. The disadvantages of these methods are also the inadequacy of the assumptions made by the physical nature of the real processes of local deformation; the necessity of accepting the hypothesis of ideal plasticity or averaging the intensity of stresses in the zone of plastic deformation; the difficulty of taking into account the contact conditions and the correct estimation of the shaping of the workpiece at each stage of rolling.

An alternative to experimental research and theoretical analysis is the use of simulation modelling of RS processes using the finite element method (FEM) [13-15].

The purpose of this study is to analyze the mechanics of shaping the workpieces by rolling stamping by finite element method and improving on its basis technological processes of RS.

Algorithm for the simulation of through technological processes in software complexes of finite-element modeling of the DEFORM-3D type for the processes of stamping by rolling is presented in Fig. 4.

Fig. 4. Algorithm for the simulation of through technological processes in software complexes of finite-element modeling of the DEFORM-3D type

RS was subject to modeling without limitation of the flow of metal along the length of the workpiece. In modeling, the initial mechanical properties for lead were given as follows: Young's modulus 2.1×10^5 MPa, Poisson's coefficient of 0.3 limit of fluidity $\sigma_{0,2} = 6$ MPa. The actual stress diagram was described as a function:

$$\sigma_s = \sigma_i(\varepsilon_i, \bar{\varepsilon}, T), \qquad (1)$$

where: $\sigma_{0,2}$ – intensity of stresses; ε_i – intensity of deformations, $\bar{\varepsilon}$ – speed of deformation; T – temperature.

Friction was taken into account on the contact surfaces of the tool and the friction coefficient was set to be $\mu = 0.08$. The deforming tool was taken absolutely rigid.

Fig. 5 shows the calculation scheme of the process of pipe workpiece flanging by RS method.
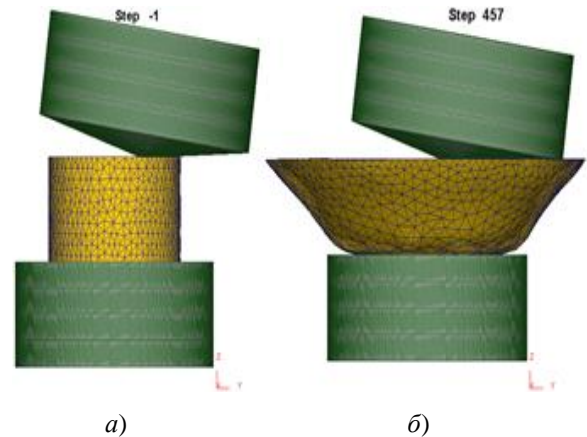

a)   *б)*

Fig. 5. Scheme of the RS process: *a* – initial position; *b* – at the moment of the established stage

In the initial position (Fig. 5*a*) 1) roll, 2) workpiece, 3) movable matrix, which moves with the workpiece in the direction of the roll along the *z* axis (Fig. 5*b*).

Computer simulation has determined the current and final geometry of the product, the stress-strain state (SSS) in the deformation center, the use of the resource of plasticity, the distribution of specific forces on the contact surface of the workpiece with the tool, as well as the dependence of the RS's effort on the movement of metal [15].

At the intersection of the channel it is visible how much the damage in the places of formation, where $\Psi_i = 0,5 – 0,55$ increases. In Fig. 6 the distribution of damage Ψ_i in the volume of deformed metal is shown.
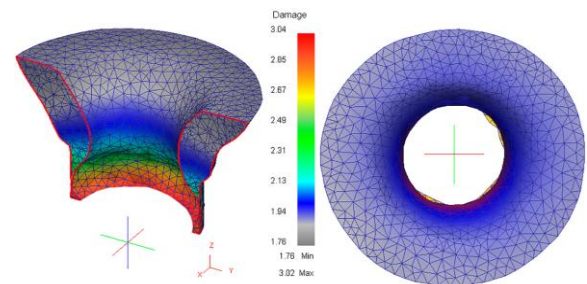

Fig. 6. The distribution of damage Ψ_i in the volume of deformed metal

The maximum value of damage was approximately 0.95 and focuses on the outer surface of the part at the exit [17]. Thus, the simulation showed the possibility to realize the process of forming the profile of the channel by the method of cold plastic deformation without damage.

The distribution of normal contact stresses on the surface of the workpiece at the point of contact with the tool is shown in Fig. 7. The maximum values of normal stresses on the instrument reach 5 MPa on the conical surface and 6 MPa on the mandrel.
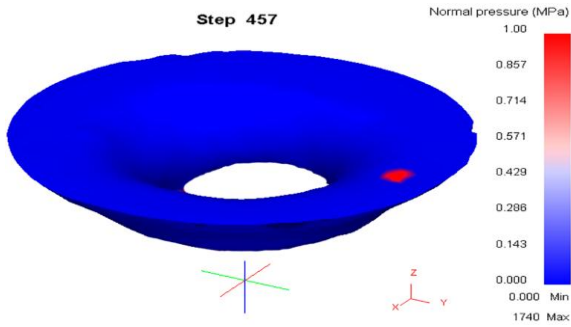
Fig. 7. Distribution of normal stresses on the contact surfaces of the workpiece with the tool

The distribution of stress intensity indicates an unfavorable nature of the stress state: the highest value of the intensity of the stresses reaches the surface layers, forming a solid "skeleton", prevents elasticity after leaving the conical area. The maximum value σ_i in the cell of the deformation of lead was 6 MPa [17].

Calculated dependence of the axial rolling force on the Poisson movement of the punch (roller) is shown in Fig. 8, with the maximum value of the process effort for lead was 25,7 kN.
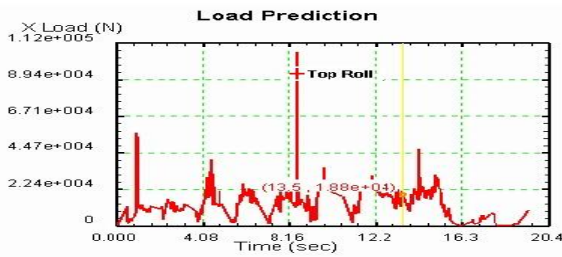

Fig. 8. Dependence of the RS's efforts on the Poisson movement (roller)

The following deformation scheme, which was to be simulated by FEM, was the formation of a profile in the RS process of workpiece on a movable mandrel. The results of simulation are presented in this work, which reflect the filling of the profile as the deformation of the workpiece by a conical roll.

Fig. 9 shows the starting position of the workpiece, when the distance between the workpiece and the roll is maximal. As the area passes through the matrix, this distance decreases (Fig.9b, 9c), and at the final stage, the gap remains only where the centering point was.
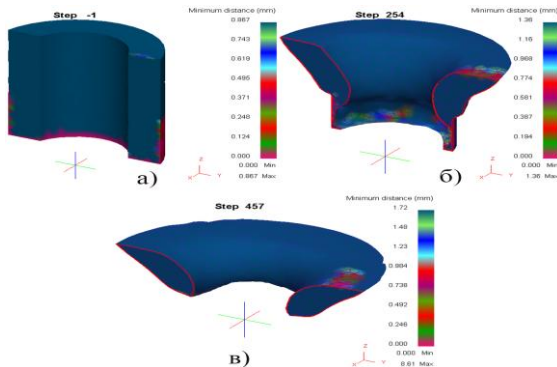

Fig. 9. Changing the maximum distance between the plane of the mandrel and the surface during the stamping process:

a – the appearance of the workpiece before the RS;
b – the workpiece on the 254 step of the RS process modeling;
c – workpiece at the final stage of simulation

It should be noted that the occipital gaps do not affect the quality of the semi-finished product of the workpiece at all, because they are subject to mechanical processing in these places.

Fig. 10 shows the distribution pattern [18], SSS in the clamp based on the results of the finite element method of RS flanging modeling for the outer ring on the tube workpiece.
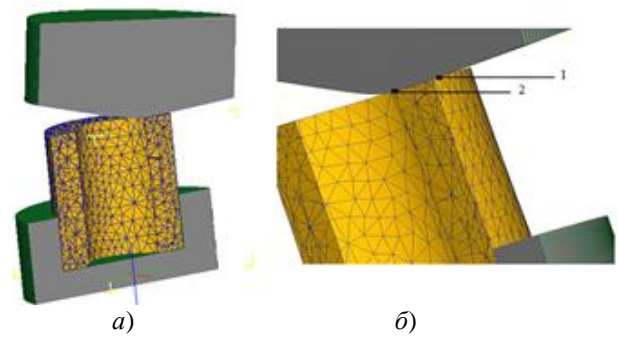

Fig. 10. The finite element method of RS flanging modeling for the outer clamp on the tube workpiece: a) calculation model; b) the location of the calculation points 1 and 2 [18]
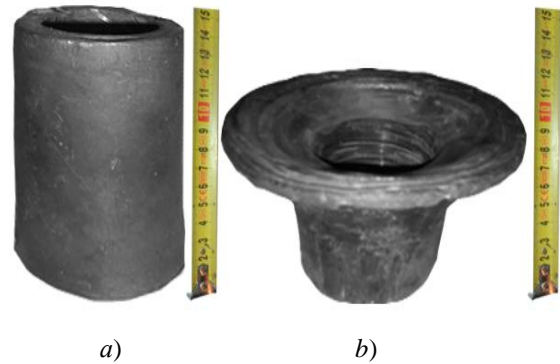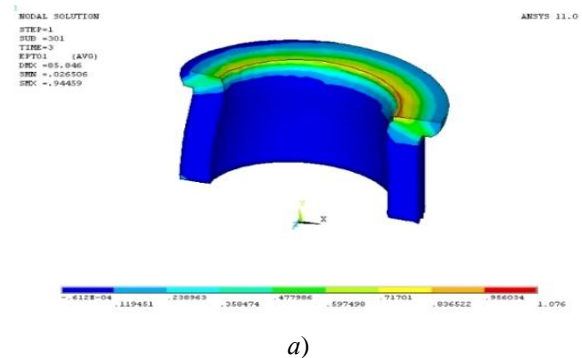

Fig. 11. Lead workpiece № 1 before RS (*a*) and after RS research (*b*)

The next RS scheme, which was to be modeled, was the upsetting of the outer clamp on the tube workpiece (Fig. 2 *b*) [17].

Figure 12 shows the nature of the formation of the clamp and the distribution of the intensity of deformations ε_i in its cross section.
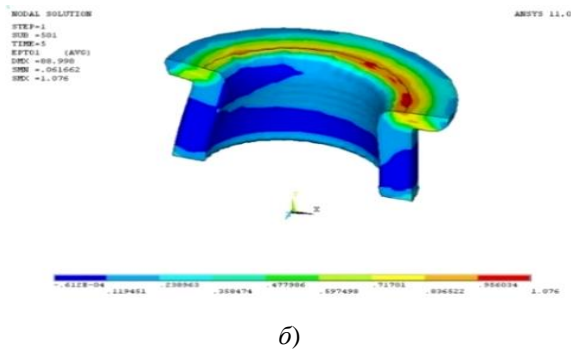

a)

б)

Fig. 12. The nature of the formation of the external clamp and the distribution of the zones of intensity of deformation in it for different degrees of upsetting by rolling a) and b) with arbitrary placement of the workpiece in the matrix

Figure 13 shows the character of the distribution of the stressed state η in the material of the clamp, where the value of the used σ_i – the plasticity resource Ψ in the metal was determined by the criterion of destruction [5].

$$\psi_i = \int_0^{e_u} \frac{de_u^*}{e_p(\eta, \mu_\sigma)}$$

(2)

where e_p – limiting deformation; $e_p(\eta, \mu_\sigma)$ is the surface of boundary deformations; e_u – the degree of deformation.

$$\eta = \frac{\sigma_x + \sigma_y + \sigma_z}{\sigma_i}$$

(3)

$$\mu_\sigma = \frac{2\sigma_2 - \sigma_1 - \sigma_3}{\sigma_1 - \sigma_3}$$

(4)

where η, μ_σ – indicators of the stress state of the material
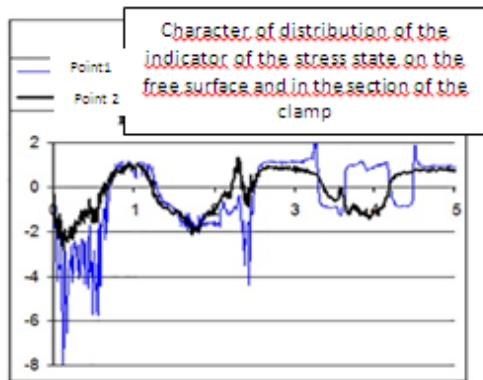

Fig. 13. Distribution of stress components and the stress state on the free surface (point 1) and in the cross section of the clamp (point 2) [18]

Results of application of the method of increasing the accuracy of the determination of boundary conditions during 3D modeling, using the results of experimental and analytical modeling of the SSS of the pipe workpiece in the RS, in accordance with the actual conditions of the form changing, is illustrated in Figs. 14-15. For a visual comparison of the results of the simulation and experimental research, Fig. 14 presents the workpiece during the experiment and as a result of simulation. From the trajectories of deformations presented in Fig. 15, which are constructed in accordance with the results of experimental research and numerical simulation of pipe workpiece, it is clear that the difference between them does not exceed the natural error of scattering of experimental data.
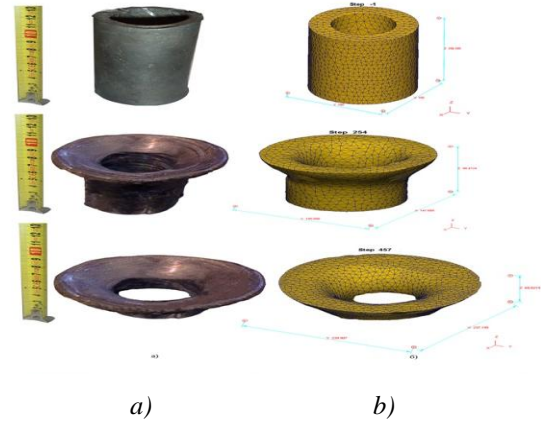

a)   *b)*

Fig. 14 RS of a lead workpiece №5: *a)* experimental research; *b)* modeling in DEFORM 3D [17]
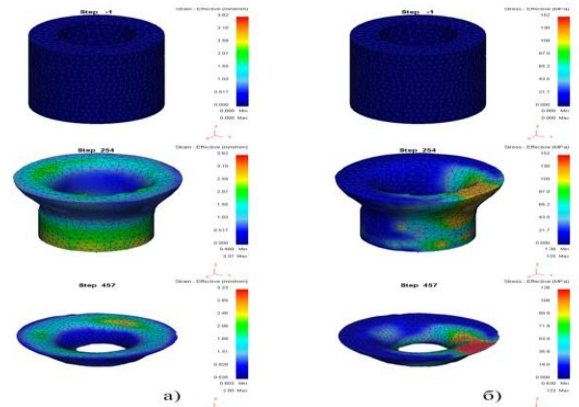

Fig.15. Distribution of accumulated deformation: *a)* intensity of stresses; *b)* during modeling of the RS process of lead sample
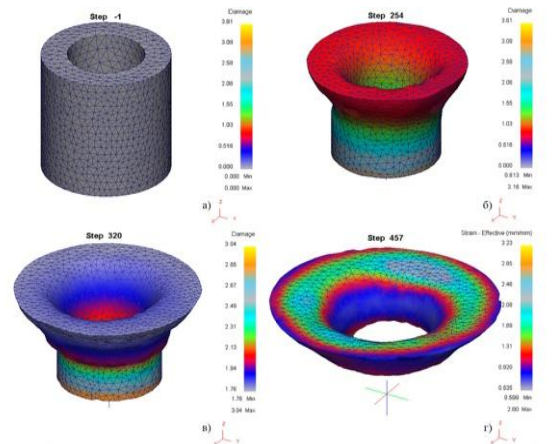

Fig.16. Distribution of accumulation of damages in the volume of pipe workpiece at RS: *a)* initial stage; *b)* at 254 steps of RS; *c)* at 320 steps of RS; *d)* the final step of deformation [18]
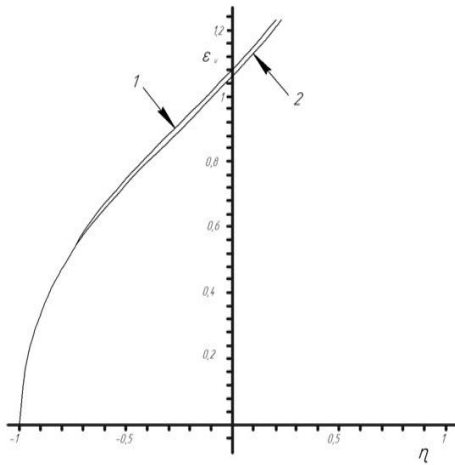
Fig. 17. Trajectory of deformation of the lateral surface of lead sample number 5: 1 – experimental study; 2 – modeling in the software package DEFORM-3D[18]

To obtain and analyze the results of SSS simulation in the meridional section of the sample, they used special commands in the DEFORM -3D postprocessor. The obtained results are presented in fig. 18.
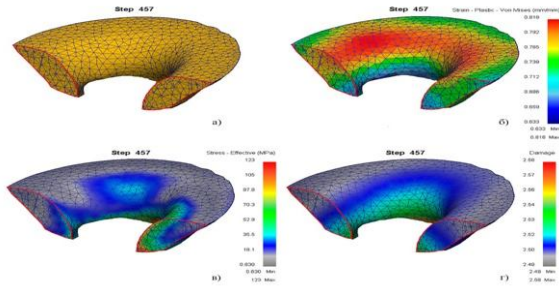

Fig. 18 *a*) Form change; *b*) distribution in the midiary section of the pipe workpiece at the final stage of the RS accumulated deformation; *c*) intensity of stress; *d*) accumulation of damage [18]

The validity of the conducted RS process simulation in accordance with the technological schemes (Fig. 2) was confirmed by the rolling of the workpieces [19]. Fig. 14 shows a part of the workpiece obtained by the RS according to the scheme of upsetting of the external clamp with $\delta > 0$ fig. 2, b. As can be seen from Fig. 12 and fig. 14, and the shape of the model is quite consistent with the form of the real detail. Fig. 14 b presents a part of the workpiece deformed with $\delta < 0$, fig. 2c, in Fig. 14 c, the part of the workpiece was obtained by the RS with the direct extrusion scheme of the deformed with $\delta = 0$, Fig. 2, *a*.

Experimental methods, such as grid method and hardness measurements, also confirmed the corresponding definition of the SSS by simulation [20].

Fig. 19. Workpieces obtained by RS method

The obtained values of the intensity of deformations and the index of the stress state allow using the criterion (2) to evaluate the deformability of the workpiece when upsetting by the RS method of external clamps for different materials [21].

CONCLUSIONS

1. The influence on the technological parameters of the mechanics of forming the workpieces has been investigated, and computer simulation of the RS process has been carried out.

2. The model defines the parameters of the use of the resource of plasticity, the final geometry of the product, the distribution of specific forces on the contact surface of the workpiece with the tool.

3. The dependence of the process's effort on the material movement is determined.

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