Stress Evaluation in the Blank Critical Region During Extrusion of the Pipe Blank into the Hole

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Abstract. The study assessed the stress state of the pipe blank in the process of extrusion into the hole. A finite element formulation of the research problem with the setting of boundary conditions in displacements and surface loading conditions is presented. The calculation of the workpiece was carried out in an elastic formulation using the Nastran engineering analysis application. The assessment of the stress state in the critical region is presented in two approximations with a thickening of the grid in the stress focus area. Based on the results of the distribution of equivalent stresses, an assessment of the unevenness of the stressed state of the workpiece was carried out. The presented study is important because it allows us to predict the appearance of defects in the process of forming a pipe billet during extrusion into a hole, to evaluate the power loading mode.

1. Introduction

To date, thin-walled constructions by the type of pipes have found wide application in the field of avistroenie in view of the requirements for the minimum weight of structures. The manufacture of thin-walled parts of complex shape is one of the important problems, the solution of which requires the improvement and development of new stamping methods. The most complete methods for solving technological problems of stamping with an assessment of the stress-strain state during plastic deformation by elastic and liquid media are reflected in the work [1]. Technologies for the production of pipe blanks based on experimental and theoretical studies are covered in the works [2,3]. In addition, a very important issue in modeling the loading of shell structures is the problem of describing the mechanical properties of materials, the behavior of the material under stresses beyond the yield point. The issues of optimization of material properties were investigated in the work [4]. The features of modeling the processes of crimping, distribution of the pipe billet are considered in [5,6].

The problems of finite element modeling of sheet blanks in the stamping process in order to predict defects: maximum refinements, corrugation are investigated in [7-9]. The issues of the distribution of equivalent stresses, deformations and damages in the area of the deformation focus are covered in [10, 11]. The problems associated with the mechanism of formation of large irreversible deformations were studied in [12].
The evaluation of force parameters during the extrusion of sheet blanks into cylindrical cross-section matrices, the non-monotonicity of the shaping process and its effect on the development of plastic deformation are reflected in [13-15]. Methods of plastic deformation of cylindrical workpieces, as well as the assessment of the deformation properties of parts in the process of plastic shaping were considered in [16,17]. The issues of assessment of deformation foci were investigated in [18].

Methods of computer modeling and optimization of sheet blanks in the stamping process were considered in studies [19,20]. In the process of forming workpieces, an important issue concerns the assessment of the uniformity of the stress state, which depends on the uniformity of the power and thermal regime of stamping, the constancy of the thickness of the workpiece. These problems were investigated in the works [21,22].

It is important to note that at present a sufficiently large number of specialized software has been developed that allows solving the problems of studying many technological processes for manufacturing parts of hydro-gas systems of aircraft. In the process of stamping sheet workpieces, the issue of predicting the focus of deformations, stress concentrators is relevant, since during the operation of the product, these areas can be sources of defects, maximum thinning. Among the computer programs that allow you to get a solution to the described problems, the undoubted leader are the MSC programs and, in particular, MSC.Nastran, which allows you to solve many problems in a short time, and also greatly facilitates their analysis.

2. Problem statement
In this study, it was necessary to calculate the stress-strain state of a thin-walled tubular billet when extruded into a hole in order to assess the uniformity of the stress state and identify critical areas. In the first approximation, for the constructed finite element grid, a calculation was carried out with an assessment of the stress state according to the intensity of stresses and the determination of the expected stress concentration zones. In the second approximation, it was necessary to reduce the step of the finite element grid in the most loaded region in order to clarify the stressed state. It was proposed to evaluate the picture of the stressed state of the shell element of the hydrogas system in an elastic formulation.

3. The methodology of the research
According to the extrusion process, the pipe billet is clamped in a matrix with a side round hole. The workpiece is affected by pressure \((q)\) from the inside and pressure \((p)\) from both ends of the pipe (Figure 1). Figure 1 shows a quarter of the workpiece, since there is symmetry with respect to the axial plane and the plane perpendicular to the axis of the workpiece passing through the center of the side hole. The hole is shown in red in the figure. Consideration of such a part greatly facilitates the calculation of the deformation process. Let's assume that the blank is a shell with a thickness of 2 mm.

To construct the geometry of the problem, a cylinder with a height of 142 mm and a diameter of 55 mm was constructed, which was then dissected into four equal parts by planes of symmetry. Then the hole into which the workpiece is squeezed was projected onto the cylinder, and the resulting projection of the cylinder was divided into eight more parts, four of which represented the free part of the workpiece (Figure 2, which shows only the contours of the cylinder and the holes). A cylindrical coordinate system was also introduced (Figure 2).

The boundary conditions in displacements and applied pressures were applied to the geometry, not to the finite element grid. According to the condition of the problem and the symmetry of the workpiece, a restriction on movement along \(Z\) in the plane \((R,T)\), a restriction on movement along \(T\) in the plane \((R,Z)\) and a restriction on movement along \(R\) of that part of the pipe that is in the matrix and does not fall into the hole is introduced. Also, in order for Nastran not to consider the workpiece as a mechanism, we introduce the fixing of one point of the workpiece located at the intersection of the planes of symmetry opposite the hole. All the above boundary conditions are shown in Figure 2. The number indicates the corresponding fixing: 1 - by \(R\), 2 - by \(T\), 3 - by \(Z\), etc. by rotational components.
relative to the cylindrical coordinate system. Figure 3 shows the vectors and magnitudes of the applied pressures.

To carry out numerical calculations on the geometry in question, a finite element grid was constructed with a given distribution of nodes at some boundaries, according to Figure 4. Moreover, the upper part of the workpiece is divided by a uniform grid, and the remaining part is uneven. The assessment of the uniformity of the stress distribution was carried out according to the coefficient of heterogeneity: $k = |(\sigma_{\text{max}} - \sigma_{\text{min}})/\sigma_{\text{med}}|$, where $\sigma_{\text{max}}, \sigma_{\text{min}}$ - absolute values of the maximum and minimum equivalent stresses, $\sigma_{\text{med}}$ - medium stress.

4. Research results and discussion

During the finite element calculation, aluminum alloy was considered as a material. Since the stress state was considered in the work in order to assess critical areas and the unevenness of stresses before plastic deformation, an ideally elastic body was adopted as a material model. The main characteristics of the material were the modulus of elasticity: Young's modulus $E = 6.9 \cdot 10^4 \text{ kg/(m:mm)}^2$, Poisson's ratio $\nu = 0.35$, yield strength $\sigma_T = 6 \cdot 10^4 \text{ kg/(m:mm)}^2$. External surface loads: $q = 200 \text{ kg/(m:mm)}$, $p = 100 \text{ kg/(m:mm)}$.

Numerical calculation of the stress state of the pipe billet during extrusion into the hole was carried out using the MSC.nastran package. As a result, the fields of normal stresses in $\text{kg/(m:mm)}^2$ in the $X,Y$ directions (Figures 5-6), as well as the distribution of equivalent stresses (Figures 7-8) were obtained.

![Figure 1. The scheme of extrusion of the workpiece in the matrix.](image1)

![Figure 2. Geometric model of the technological process.](image2)
Figure 3. Geometric model and boundary conditions in pressures.

Figure 4. Finite element model of the workpiece.

Figure 5. Voltage field (component x)

Figure 6. Stress field (component y)
Figure 7. Stress field (according to Mises).

Figure 8. Stress field (according to Mises with differences in finite elements).

Figure 8 shows the stresses in the differences between adjacent finite elements. This figure shows the presence of a critical area for calculation (at the top of the hole), since the voltage differences are of the same order as the stresses. Therefore, it is necessary to compact the grid in the critical area as shown in Figure 9. The results of stress distribution in components X,Y and stress intensity are presented in Figures 10-12.

Figure 9. Compacted finite element model.

Figure 10. Stress field (according to Mises).
According to the calculation results, the maximum equivalent stresses do not exceed the yield strength, which eliminates the appearance of irreversible deformations. With the thickening of the grid, the order of differences in stresses by elements has not changed, but the magnitude of stresses in the critical region has increased. In addition, for each finite element in the critical region, after repeated sampling, there is a smaller "drop" in voltage.

The stress concentration in the critical region is due to the complexity of the geometry and in relation to the minimum stress is 1.36. When recalculated with the grinding of the grid, the stress intensity in the critical region increased by 42%. The coefficient of inhomogeneity of the distribution of equivalent stresses of the workpiece under surface loading is 0.55.

5. Conclusion
Thus, the finite element calculation carried out on the extrusion of a part of a thin-walled tubular billet into the hole made it possible to determine the critical area of the pipe billet, which is the part of the billet where there are significant stresses. Finite element calculation in two approximations with the thickening of the grid in the stress concentration region allowed us to obtain a more accurate picture of the stressed state of the pipe billet. The calculation results will make it possible to predict a potentially defective area with an increase in load.

6. References
[1] Isachenkov E I 1967 Rubber and liquid stamping Publisher: Mashinostroenie 370
[2] Azhazha V 2006 Production of the Batch of Pipe Billets for Trex-Pipes and Experimental-Industrial Batch of Pipes of Zr1Nb Alloy from Domestic Raw Materials Nauka ta innovacii 2 pp 18-30 10.15407/scin2.06.018
[3] Danchenko N, Kolikov A P, Romantsev B A, Samusev S V 2002 The technology of the rolling manufacturing 640
[4] Odinokov V I, Dmitriev E A, Evstigneev A I, Sviridov A V, Ivankova E P 2020 Modeling and Optimizing the Property Choices of Materials and Structures of Shell Molds for Investment Casting Steel in Translationthis link is disabled 50(10) pp 684–695
[5] Romanov P V, Blagochinnov R S 2021 Modeling of the process of obtaining eccentric adapters by combining crimping and extrusion operations News of Tula State University. Technical sciences 5 pp 97-102
[6] Potianikhin D A, Maryn B N, Feoktistov S I, Soe K Z 2019 Simulation of thin-walled workpieces ends expanding for pipelines making *IOP Conference Series: Materials Science and Engineering* **510**(1) 012015

[7] Andrianov I, Stankevich A 2019 The stress-strain state simulation of the aircraft fuselage stretch forming in the ANSYS *Journal of Physics: Conference Series* **1333** 082002 10.1088/1742-6596/1333/8/082002

[8] Mitin O N, Yakovlev S S 2015 Computer simulation of the combined operations of crimping, crimping with thinning and back extrusion walled round billets *Forging and stamping production Processing of materials by pressure* **10** pp 14-20

[9] Andrianov I K, Stankevich A V 2019 Finite-Element Model of the Shell-Shaped Half-Pipes Forming for Blanks Behavior Investigating During Corrugating at the Stamping 2019 *International Science and Technology Conference "EastConf"*, EastConf 2019 8725322 pp 1-3 10.1109/EastConf.2019.8725322

[10] Vorontsov A L, Rechikov E O 2021 Radial extrusion of a pipe billet with internal protrusion definition of kinematic and stress states *Engineering Journal with appendix* **4** pp 11-17

[11] Platonov V I, Yakovlev S S, Isaeva A N, Larina M V 2013 Distribution of equivalent stresses, deformations and damage in the deformation focus during isothermal reverse extrusion of anisotropic pipe blanks *Proceedings of Tula State University. Technical sciences* **6** pp 49-56

[12] Begun A S, Burenin A A, Kevtanyuk L V, Lemza A O 2020 On the mechanisms of production of large irreversible strains in materials with elastic, viscous and plastic properties *Archive of Applied MechanicsThis link is disabled* **90**(4) pp 829–845

[13] Pankratov I 2014 The use of the software product deform 3d to determine the stress-strain state of precision engravings stamping dies The Youth of the 21st Century: Education, Science, Innovations Proceedings of the International Conference for Students, Postgraduates and Young Scientists Vitebsk VSU named after P.M. Masherov pp 29-30

[14] Evstratov V A 2007 The use of the principle of expansion of the focus of plastic deformation during stamping and extrusion *Forging AND stamping production Processing of materials by pressure* **2007** **12** pp 18-21

[15] Hamin O N 2020 Approximate estimation of force parameters during stamping by extrusion of hollow blanks *Modern materials, equipment and technologies* **5**(32) pp 128-134

[16] Pasynkov A A, Pasynkova N S, Palchun E N 2020 Analysis of power modes of reverse extrusion of a rod blank into a cylindrical cross-section matrix *Izvestiya Tula State University Technical sciences* **4** pp 404-409.

[17] Rozov Yu G 2013 The influence of the nature of the temperature distribution in the volume of a pipe billet on the heterogeneity of the deformation resistance field in sheet stamping operations *Izvestiya Tula State University. Technical sciences* **7-2** pp 36-43

[18] Chumachenko E N 2008 Computer simulation and optimizing the stamping of aluminum- and titanium-alloy parts on the basis of superplasticity *Russian Engineering Research* **T 2** **5** pp 454-460

[19] Chumadin A S, Shemonaeva E S 2020 Producing parts of uniform thickness from sheet of variable thickness *Russian Engineering Research* **T 40** **6** pp 522-525

[20] Vorontsov A L 2019 Production of large disks from cylindrical blanks by plastic deformation. introduction of central punch to create a depression *Russian Engineering Research* **T 39** **7** pp 567-570

[21] Sosenushkin E N, Yanovskaya E A, Sosenushkin A E, Emelyanov V V 2015 Mechanics of nonmonotonic plastic deformation *Russian Engineering Research* **T 35** **12** pp 902-906

[22] Kutanov S V 2011 Deformation and mechanical properties of components produced by plastic shaping *Russian Engineering Research* **T 31** **12** pp 1239-1241