

STRESS STATE OF A TOOL FOR STAMPING TUBES

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Abstract

The presented work is devoted to analysis of the stress-strain state and restoring repair of stamping tools, intended for forming large-diameter tubes, based on computer modeling. Stamping tools includes in its membership a stamp holder and eight interchangeable cast-iron liners, which have a cylindrical surface with radius, equal to the radius of the tube, and are established on the stamp holder. The load out of the deformed billet of tube is transferred on the cylindrical surface of the tool and further to the bearing surfaces of the stamp holder. Contact interaction occurs between the parts of stamping tools, and it affects on they stress-strain state. To solve the nonlinear boundary problem of elasticity theory is used a numerical finite element method.

Key words: Holder stamp, liner, low cycle fatigue, boundary problem, computer simulation

1. INTRODUCTION

Manufacturing of steel longitudinal welded tubes with diameter from 530 mm to 820 mm at the Chelyabinsk Tube Rolling Plant is performed by the so-called technology UOE. Figure 1 shows the cross section of the die for forming tubes of this technology in its final stages.

The stamp has two identical parts- upper and lower; the upper part performs reciprocating motion in the vertical direction, while the bottom part is fixed. A preform is transformed from a U-shaped in a ring during the process of deformation. External load is transferred from the billet on the liners and stamp holder and leads to a change in their size and shape. In the first stage of deformation, the upper edge of the billet is in contact with the top liner and moves on its cylindrical surface. Part of the billet, which is located between the upper and lower liners, is slightly bent, and differs little from a straight line. The value of force, which is transferred from the billet on the liner at this stage of deformation, can be determined based on the ratio:

$$F_l = \frac{\sigma_m \cdot \delta^2 \cdot l_z}{l \cdot [\sin \varphi + \cos \varphi \cdot tg(\psi + \lambda)]}, \quad (1)$$

where δ - thickness of the billet, l_z - billet length, l - distance from the pre-curved bottom section of the U-shaped piece to the edge of the sheet, σ_m - yield strength of billet material, φ - the angle between the sidewall and the vertical axis, ψ - the angle between the normal to the surface of the liner at the contact edge of the formable tube and a vertical line, λ - angle of friction between the billet and the liner.

The second stage of the forming of tube is characterized by obtaining a cylindrical shell as a result of convergence of the opposite liners. The maximum value of the efforts of forming of billet on the

second operation is twice more than the load, reached at the first stage. Right fragment of Fig.2 shows the end of the second stage of deformation of the billet. It is evident, that the initial U-shaped cross-section of a billet was transformed into a ring, but to complete the process of forming the pipe should be at all points of the cross-section to enforce the conditions under which the intensity of the stresses exceed the yield stress of billet material. It is obvious that the initial U-shaped cross-section of a workpiece has been transformed into a ring, but to complete the process of forming the tube, it is necessary to provide conditions, under which the intensity of the stresses exceeds the yield stress of workpiece material on the entire cross section of a mouldable tube.

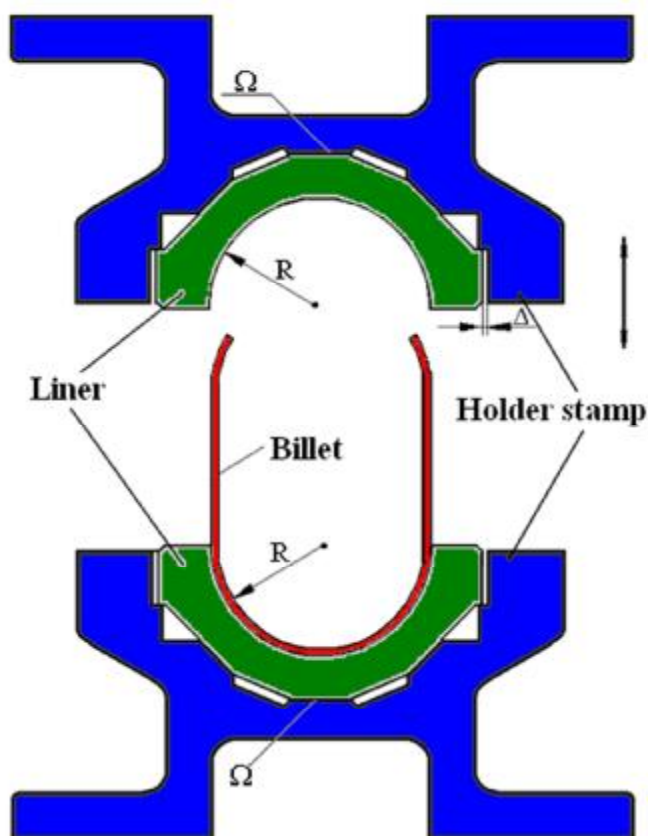


Fig.1 Cross section of the stamp

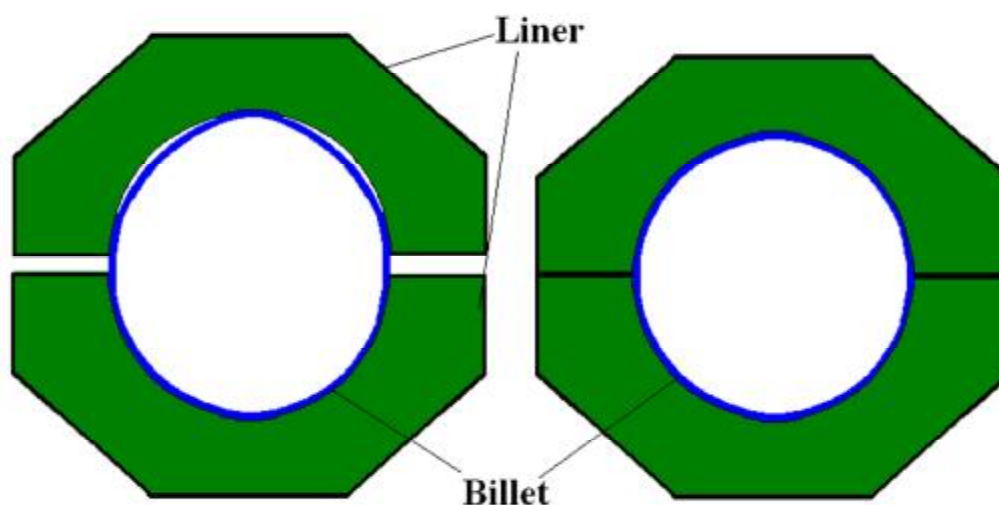


Fig.2 Operation of forming a cylindrical tube

This condition is provided in the third stage of deformation of the billet. The latter operation is characterized by a sharp increase of load, which is transmitted to the tool from the workpiece. This has been proved theoretically and was observed in experiments, with using pressure gauges. At the end of the process of forming a cylindrical tube, the value of pressure of the fluid in a hydraulic press more than five times higher, than analogical value at the end of the second operation. This increased pressure is necessary for ensurance of plastic deformation around the perimeter of the pipe. On the basis of calculating the stress state of billet, taking into account the physical nonlinearity, was obtained maximum load intensity p .

$$p = \frac{2\sqrt{3} \cdot \sigma_t \cdot \ln(1 - \frac{2\delta}{D_H})}{3} \quad (2)$$

where D_H –outer diameter of the formable tube.

All stages of the final forming of tubes are performed on a powerful hydraulic press with pressing force up to 200 MN [1]. Pressure of hydraulic press allows to mold the billet with a wall thickness of 12 mm. However, the practice of exploitation of the stamp showed, that the tools have no the sufficient resource, even during the formation of pipes with wall thickness of 10 mm. The result of low cycle fatigue is the loss of bearing capacity of the stamp tools. The holder stamp has a long structure, which consists of two parts, connected together by bolts. On Fig. 3 is shown only one part of the holder stamp. Each part has a length of 6 meters and consists of ten hard ribs. Eight of them - the intermediate ribs have a width of 130 mm and located a distance of 515 mm from each other. On the inner surface of the holder stamp there are two vertical planes, the two inclined planes and one horizontal plane. These support planes is designed for installation of liners.

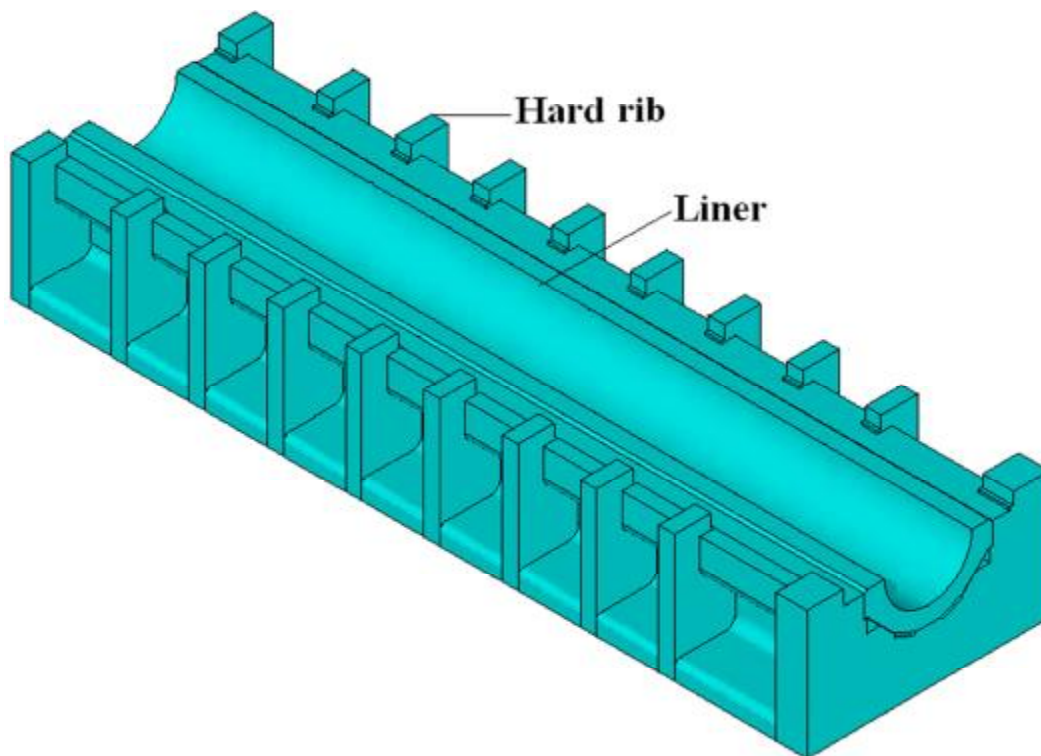


Fig.3 Individual components of holder stamp

There is a guaranteed gap Δ between the vertical surface of the liner and the holder of the stamp (see Fig.1). It can be selected during deformation of the billet. After selecting the gap, there is the contact interaction between the liner and the holder stamp on a horizontal plane and vertical planes. This leads to a significant change in the stress-strain state of the liner and of holder stamp. These changes should be considered in the process of developing a mathematical model. However, such an inclusion leads to a structural nonlinearity. Stress-strain state of the stamping tools is described by the theory of elasticity with nonlinear boundary conditions arising from the choice of the gap and subsequent contacts. Stress-strain state of the stamping tools is described by the theory of elasticity with nonlinear boundary conditions, which are caused by the choice of the gap and subsequent contacts. Consequently, for its definition, it is necessary to solve nonlinear boundary value Cauchy problem. Analytical methods for calculating problems of this type do not currently exist. In the papers [4,5] was presented an approach, based on reducing the initial spatial problem of elasticity to the solving of the plane problem. This approach presupposes that the differential equations can be analytically integrated. This assumption does not fully takes into account the geometry of the stamping tools, which directly affects the size of the contact area between the liner and the holder stamp and, therefore, does not give reliable results.

2. THE SOLUTION OF THE NONLINEAR PROBLEM

The finite element method was used to solve nonlinear boundary value problem of elasticity theory. This method was implemented as a software package for personal computer. Simulation of shamping tools was carried out using volumetric finite element with eight nodes and twenty-four degrees of freedom. Three displacements in the direction of the axes of a spatial Cartesian coordinate system

have been the unknown values at each node of the finite element. Simulation of the contact area was carried out using special contact element. This element takes into account the geometry, relative position of the contacting bodies and the initial gap between them. At the initial step of the iterative process associated with the solution of the nonlinear problem of contact interaction, we assumed that the gap between the vertical planes of the contacting bodies is known. In the nodal points lying in the plane of the possible contact of both bodies are taken into account two forces: the normal force and frictional force, which is defined as the product of the normal force on the friction coefficient. To calculate these forces, the coordinates of the contacting bodies and their displacements have been identified previously. Through the coordinates of the contact element can be calculated relative displacement of nodes, belonging to different bodies, and compare it with the magnitude of the gap. If the relative displacement of nodes exceeds the value of the gap, then the bodies start to interact with each other. In this case, the interaction forces are proportional the value, which equal the difference between the relative displacement and the initial gap. Finite element computational model is used to determine the stress-strain state of stamping tools is shown in Figure 4. The model contains 68,046 nodes, 291,978 volume finite elements and 34,764 contact element. The value of surface load, determined on the basis of relations (2), and this load was applied to the cylindrical surface of the liner. In all nodal points of the holder stamp on the bottom of the horizontal plane, imposes restrictions on all movement. The gap between the vertical plane of the insert and holder of the stamp was taken as 0.3 mm. Yield strength of workpiece material amounted to 470 MPa, the thickness of workpiece 10 mm, outside diameter of tube - 820 mm.

Mechanical characteristics of materials of stamping tools are listed in Table [7]:

Detail of stamping tools	Liner	Holder stamp
Material	Cast iron BЧ-50-1,5	Steel 30J1
Elastic modulus, GPa	175	200
Poisson's ratio	0,27	0,3

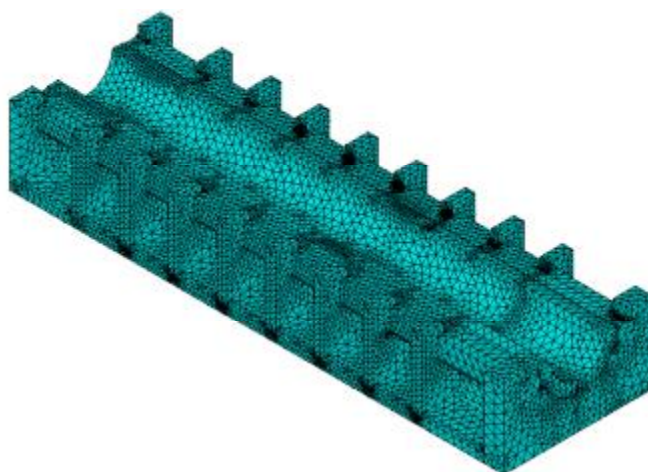


Fig.4 The finite element computational model of stamping tools

3. THE RESULTS OF CALCULATIONS

On Fig. 5 the mosaic of the von Mises equivalent stresses in the liner is shown. Left fragment of Fig.5 characterizes the stress distribution along the cylindrical surface of the liner. Right portion of the image in Figure 5 characterizes the distribution of stresses in the cross section of liner. The initial undeformed shape of the liner is shown of the dashed line. Certain interval of equivalent stresses corresponds to each color on the scale, which is takes place on the submitted figure.

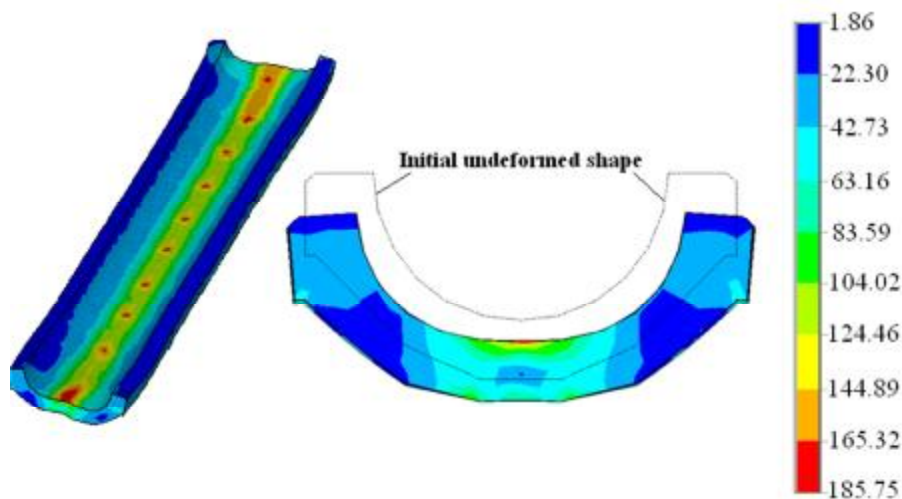


Fig.5 Mosaic of equivalent stresses in the liner, MPA

It is seen, that the region of maximum of equivalent stresses, marked in red, is located on the inner surface of the liner, in areas opposite zones of direct contact of liner with the ribs of the stamp holder. In the themselves contact zones of the liner and the stamp holder, the maximum value of equivalent stress does not exceed 124.5 MPa. The deformed shape of the liner shows that the formation of tubes is accompanied by bending of the liner and its displacement together with the stamp holder. In this case, the initial gaps between the contacting bodies on the horizontal and the vertical plane, was selected. The equivalent stresses on the vertical plane of contact in the liner, presented in Fig.5, is much smaller than on the horizontal plane. Such a significant difference due to the fact, that the stiffness of the stamp holder rib in the horizontal direction is much lower than in the vertical direction.

On Fig.6 is shown a picture of the equivalent von Mises stresses in the stamp holder. The upper left portion of this figure corresponds to an isometric view on the stamp holder, and right upper fragment corresponds to the view from below. At the lower segment Fig.6 is shown the distribution of equivalent stresses in the cross section of the holder stamp, the initial shape of the cross section is shown the dotted line. The each color tint on a mosaic of equivalent stresses corresponds an interval on the scale stresses.

It is seen, that the largest equivalent stresses takes place in a relatively narrow region, located at the junction between the ribs and the horizontal plane, their maximum value is 281.2 MPa. On the opposite surface of the stamp, the maximum equivalent stress is 247.3 MPa. The ribs have a significant effect on the stress-strain state of the holder stamp, the equivalent stresses in the places of their location significantly less than in other parts of the structure. The magnitude of equivalent stresses in these ribs do not exceed 63 MPa. Since the value of maximum equivalent stress exceeds the yield strength of steels 30 JI, equal to 260 MPa, the irreversible plastic deformations appears and

increases with the increasing number of loading cycles in the areas of the holder stamp, which was designated above.

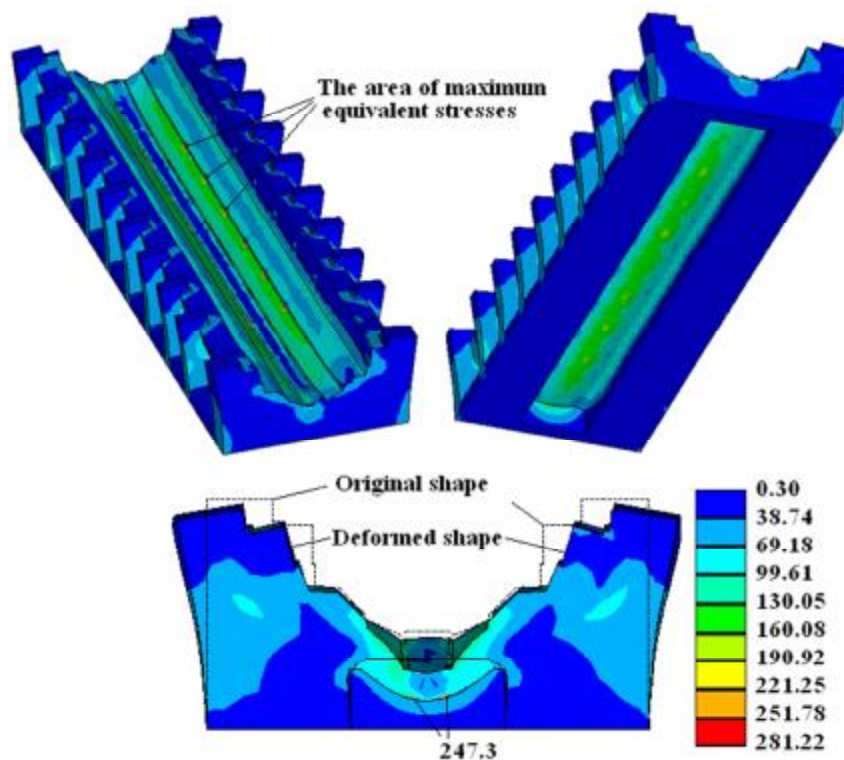


Fig.6 Picture of equivalent von Mises stresses in the stamp holder

When the magnitude of accumulated plastic strain exceeds the allowable value of the intensity of deformation, the formation and further extension of cracks in the material of the holder stamp will begin to occur. With an increasing number of cycles of mechanical loading the plastic strains grow up to crack formation. Low-cycle fatigue theory can be applied for the calculation of resource of the stamp holder. It takes into account the influence of the number of loading cycles on the accumulation of plastic strain. An equation, which takes into account anticipated impacts, is presented below [6]:

$$e_{ia} = \frac{0,5}{[(1-\psi) \cdot N]^{0,6}} + \frac{1,75 \cdot \sigma_{\epsilon}}{E \cdot N^{0,12}} \quad (3)$$

where e_{ia} - peak value of strain intensity, N - number of loading cycles, ψ - the coefficient of contraction of the material liner, E - modulus of elongation of the material, σ_{ϵ} - the value of the tensile strength of the material. Curve of low cycle fatigue Steel 30L, obtained using (3) is shown in Fig. 7.

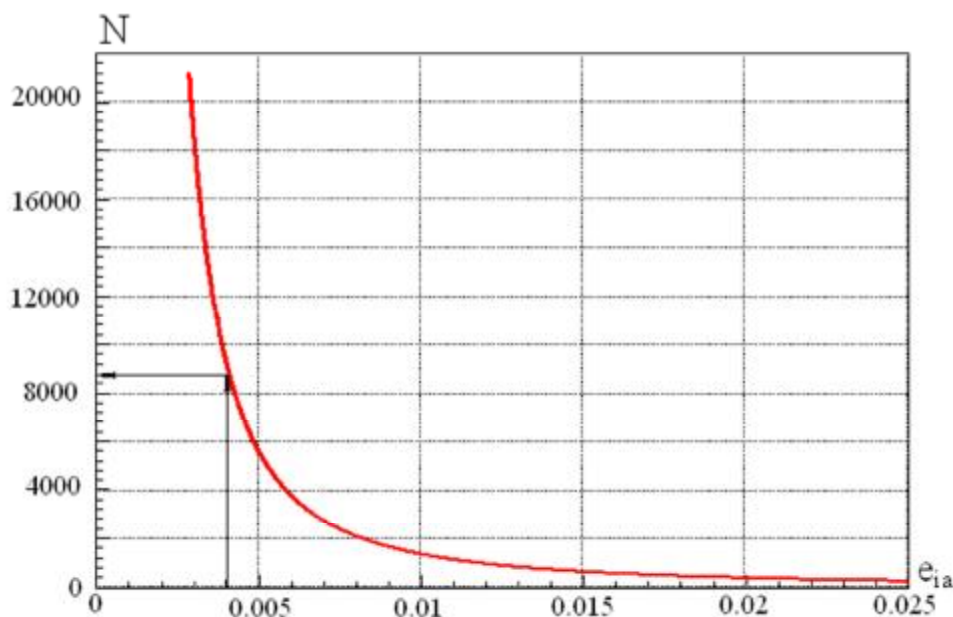


Fig.7 The curve of low cycle fatigue Steel 30J

For Steel 30J largest calculated value of the strain intensity is equal $e_{ia} = 0,00863$;

$$\psi = 30\%; \sigma_e = 480 \text{ MPa.}$$

The calculated peak value of strain intensity, which is corresponded to the maximum value, allows to determine the number of loading cycles before loss of bearing capacity of the stamp holder by using of the low-cycle fatigue curve. The abscissa of a point of intersection of a vertical straight line $e_{ia} = 0.0041$ with the low-cycle fatigue curve corresponds to the value of $N = 8664$.

The estimated resource of the stamp holder has been exceeded during the stamp tool exploitation. This has led to its destruction with the formation of cracks in the horizontal plane of contact. Manufacturing of new stamp holder requires huge, time and material resources. It was proposed to perform the repair of the holder stamp with the simultaneous modernization. In order to reduce the stresses was proposed to increase rigidity of the holder stamp. The plates with thick 40 mm was attached by welding at an angle of 45° to the longitudinal axis to the horizontal plane Ω of the holder stamp. The height of the ribs on 20 mm less than the depth of the lower cavity, this is necessary to avoid contact between this ribs with the base of the lower holder stamp. According to the method mentioned above, we calculated the stress-strain state of the upgraded design of the stamp holder. Mosaic equivalent stresses in the repair option of the holder stamp are shown in Fig. 7.

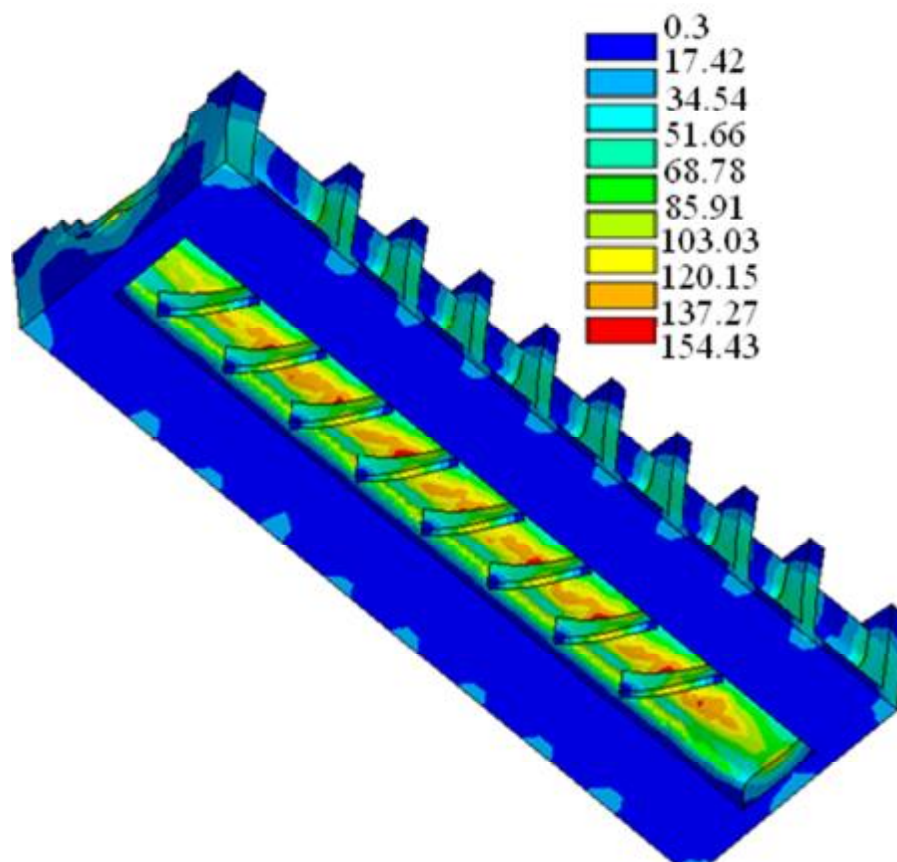


Fig.7 Picture of equivalent stresses in the holder stamp upgraded version of the design, MPa

It is seen, that the highest equivalent stresses observed in the junction zone plate with a stiffener. However, the magnitude of these stresses does not exceed 154.43 MPa and significantly less than the yield strength steel 30 JI. The value of equivalent stress in the contact zone between the liner and stamp holder is equal to 198.3 MPa and almost 30% less, than the same values in the original design.

CONCLUSION

A method for analyzing the stress-strain state of the stamp holder of the press for forming of large diameter tubes has been presented in this paper. The method is based on the nonlinear boundary-value problem of elasticity theory with using of the finite element model implemented in a software package. This method allows to choose a rational scheme to strengthen construction of the stamp holder during its modernization, which reduces the intensity of the equivalent von Mises stresses by 30% compared to the previous design. This fact served as the basis for the adoption of the developed scheme in the "Chelyabinsk Tube Rolling Plant".

REFERENCES

1. Chechulin Y.B., Fedorov A.A., Goncharov K.A., Kauzov A.M. Ways of increasing the durability of punching tool for forming longitudinal welded large diameter pipes. // Proceedings of the II

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- International Scientific-Technical Conference Rouault AES RF "On the cutting edge of science and engineering creativity." Ekaterinburg: Ural State Technical University, 2000 - P.358-360.
2. Fedorov A.A., Goncharov K.A., Chechulin Y.B. Improving resource stamping tools for forming welded large diameter tubes. // Steel .- 2000 - № 12.-p.41-44.
 3. Goncharov K.A., Chechulin Y.B. Investigation of the stress state of a sheet blank in the manufacture of large diameter tubes. // Abstracts of the Scientific Conference "Designing scientific and engineering applications in MATLAB". M: MATLAB, 2002 - P.61-62.
 4. V.A. Kozlov, V.G. May'za and A.V. Fomin, An iterative method for solving the Cauchy problem for elliptic equations, Comput. Maths.Phys. 1 (1991), P.45–52.
 5. Dautray, R., Lions, J.L.: Mathematical Analysis and Numerical Methods for Science and Technology, vol. 2. Functional and Variational Methods. New York: Springer–Verlag, 1988
 6. Sorensen S.V. Strain field in the low-cycle loading. Moscow: Nauka, 1979. -277p.
 7. Materials in engineering. Ed. I.V. Kudryavtsev. - Moscow: Mashinostroenie, 1969. – 248p.