

EXPANSION OF PIPE AS OBJECT FOR MATHEMATICAL MODELING

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Abstract: Modeling stress and strain fields must precede designing innovative technologies forming tube workpieces, which makes it possible to assess their ultimate limit states. Analytical dependences of stresses in the wall of the tube workpiece, the technological parameters and the basic relations for the evaluation of strains and displacements are received. Reliability of the results is confirmed by experiments.

KEYWORDS: TUBE WORKPIECES, HOLLOW PRODUCTS WITH FLANGES, TAPERED PRODUCTS, MATHEMATICAL MODEL, THE DISTRIBUTION, THE STRESS-STRAIN STATE.

In many industries, such as power engineering, automotive, construction industry, chemical industry, oil and gas industry, hollow products with conical surfaces and tubular goods with flanges are used. The first group of components use in the installation of pipelines, to provide proceeding from one diameter to another, for the purpose to change the flow rate of the fluid or gas. The second group provides connections of various branches of the pipelines when their direction is changing. Therefore research, devoted to improve the technology of forming these products, is actual.

The traditional process of manufacturing these products are expansion of pipe, pinch, and their combinations [1-3]. In expansion of pipe the plastic deformations concentrate only in the part of workpiece – the deformation region, while the rest of the workpiece is in elastic or, at least, in the plasto-elastic state. When the expansion of pipe performs, it is necessary to strive to increase the size of the deformation region to provide increasing in the forming workpiece without displaying unwanted defects: the destruction of the workpiece during deformation, loss of stability of the workpiece, resulting in distortion of the given form, which has illegal changes of material thickness in conditions of manufacture of the product [4]. Workpiece in the expansion of pipe is generally a spatial cover. Elements of cover make spatial displacement under the action of only one instrument - the punch in contact with inner surface of cover. So the absence of stresses on the free surface can be considered as boundary conditions. Since process the deformation is not stationary, then the solution to determine the stress and strain fields for the assessment of possible deformation should be in accordance with the theory of flow[5]. Differential equations of equilibrium and plasticity condition is used as the converted analytic functions depending the mechanical properties on the strain or the strain rate with approximate calculation for non-stationary process and boundary conditions. For a schematic of the process of power action we take a cylindrical coordinate system. The main assumptions are: material of workpiece is a rigid-plastic, incompressible, transversely isotropic, obey the condition of Mises-Hill' plastic flow.

Since the shaping of a flat flange on the pipe billet pre-transition (one or more) distribution conical punch with different taper angles φ and due to the large range of pipe transitions that have tapered sections, then, considering the state of stress in an axisymmetric cylindrical coordinate system, select an infinitesimal the volume of the deformable membrane, located on the conical section of the punch. In general, the axis of the conical section or axis of the flange can be located on the axis of the tube workpieces at a certain angle γ . Perpendicular arrangement of the flange to the axis of the workpiece when $\gamma = \frac{\pi}{2}$ or coaxial arrangement on the conical section of the original workpiece when $\gamma = 0$ is more common.

In Fig. 1, an infinitesimal element of conical cover volume with an inclination axis $\gamma < \frac{\pi}{2}$ shows, one of the faces of which is

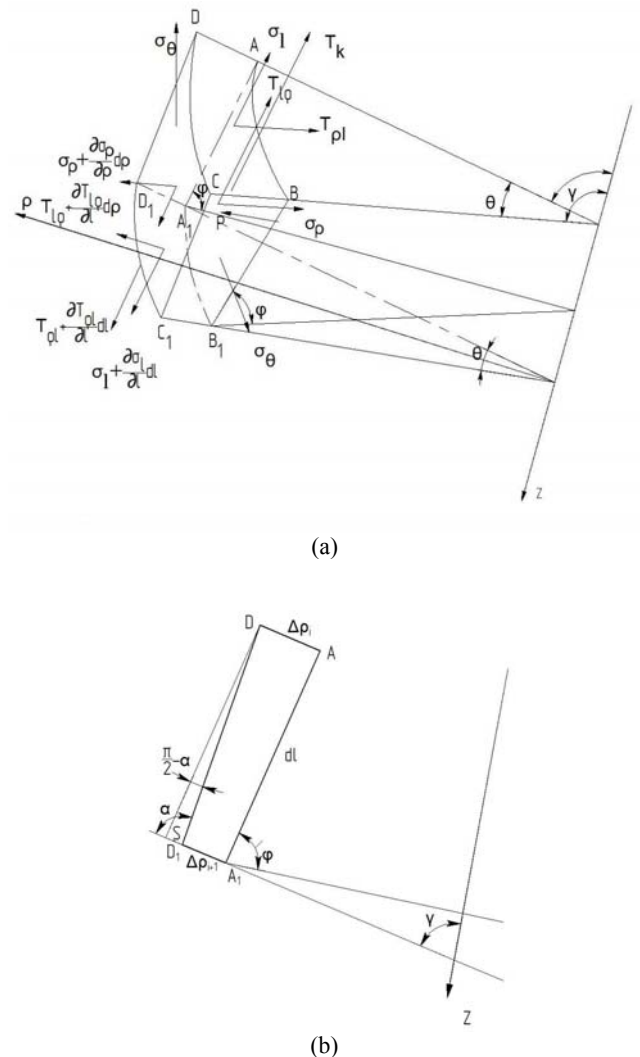


Fig. 1. The stresses in the voluntary unit of conical cover with the rotation its axis relative axis of tube workpiece at a given angle γ (a), the geometric parameters of edge AA_1D_1D selection (b).

shown in Fig. 1, b. Forming a conical section is uneven distribution of the first transition stamping.

When we project the forces on the edge of the selected element on a tangent to the forming a conical surface, we obtain the differential equation of equilibrium:

$$(1) \quad -\rho d\rho \cdot d\theta \cdot \sigma_l + (\rho d\rho - \rho dl \cdot ctg\alpha + d\rho \cdot dl(ctg\varphi - ctg\alpha))d\theta(\sigma_l + \frac{\partial \sigma_l}{\partial l} dl) - \rho \cdot dld\theta \cdot \beta \cdot \sigma_s \cdot \mu = 0$$

After the transformation and removal of members of the higher orders, because they are small, we obtain a linear differential equation:

$$(2) \quad \frac{\partial \sigma_l}{\partial l} - \left(\frac{ctg\alpha}{\Delta\rho} - \frac{1}{\rho}(ctg\varphi - ctg\alpha) \right) \sigma_l - \frac{1}{\Delta\rho} \beta \cdot \sigma_s \cdot \mu = 0;$$

after transformation

$$(3) \quad \frac{d\sigma_l}{dl} - \Phi \sigma_l - F_{TP} = 0,$$

$$\text{where } \frac{\rho \cos \alpha \sin \varphi - \Delta\rho(\sin(\alpha - \varphi))}{\rho \sin \alpha \cdot \sin \varphi} = \Phi(\rho, \alpha, \varphi).$$

Integrating, we obtain

$$(4) \quad \sigma_l = C_l \exp\left(\frac{\rho \cos \alpha \sin \varphi - \Delta\rho \sin(\alpha - \varphi)}{\rho \sin \alpha \sin \varphi}\right) - \frac{\rho \sin \alpha \sin \varphi \cdot \beta \cdot \sigma_s \cdot \mu}{\cos \alpha \sin \varphi - \Delta\rho \sin(\alpha - \varphi)}$$

To determine the constant of integration, we use the boundary conditions:

$\rho = R$; $\sigma_l = 0$; $\Delta\rho = 0$. In this case,

$$C_l = tg\alpha \cdot \beta \cdot \sigma_s \cdot \mu \cdot \exp\left(-\frac{1}{\Delta\rho \cdot tg\alpha} + \frac{l \sin(\alpha - \varphi)}{R \sin \alpha \cdot \sin \varphi}\right),$$

meridional stresses

$$(5) \quad \sigma_l = tg\alpha \cdot \beta \cdot \sigma_s \cdot \mu \cdot \exp\left(\left(\frac{\rho \cos \alpha \sin \varphi - \Delta\rho \sin(\alpha - \varphi)}{\rho \cdot \Delta\rho \cdot \sin \alpha \cdot \sin \varphi} - \frac{1}{\Delta\rho \cdot tg\alpha} + \frac{\sin(\alpha - \varphi)}{R \sin \alpha \sin \varphi}\right)l\right) - \frac{\rho \sin \alpha \sin \varphi \cdot \beta \cdot \sigma_s \cdot \mu}{\rho \cos \alpha \sin \varphi - \Delta\rho \sin(\alpha - \varphi)}$$

We write the second equation of equilibrium as a projection of the forces on the normal to the conical surface

$$(6) \quad (\rho + d\rho)dl \sin \alpha \cdot d\theta(\sigma_\rho + \frac{\partial \sigma_\rho}{\partial \rho} d\rho) - \rho dld\theta \sigma_\rho + \rho dld\theta \frac{d\rho \sigma_\theta}{\rho} - 2\sigma_\theta \frac{d\theta}{2} d\rho dl = 0$$

After the transformation and removal of members of the higher orders, because they are small, we get

$$(7) \quad \frac{\partial \sigma_\rho}{\partial \rho} = \left(-\frac{1}{\Delta\rho} - \frac{1}{\rho} + \frac{1}{\sin \alpha \cdot \Delta\rho}\right) \sigma_\rho$$

Separate the variables and integrate the equation

$$(8) \quad \sigma_\rho = C_\rho \cdot \frac{1}{\rho} \cdot e^{\frac{\rho(\sin \alpha - 1)}{\Delta\rho \sin \alpha}}.$$

With initial conditions: $\rho = R_0$, $\sigma_\rho = 0$, with $\Delta\rho = \Delta R$, integration constant must be set $C_\rho = 0$; where R_0 – radius of workpiece.

To determine the unknown circumferential stress σ_θ we use plasticity condition:

$$(9) \quad \sigma_\theta^2 - \sigma_l \sigma_\theta + \sigma_l^2 - \sigma_s^2 = 0.$$

We solve the equation of plasticity (2.17) relatively σ_θ :

$$(10) \quad \sigma_\theta = \frac{\sigma_l \pm \sqrt{4\sigma_s^2 - 3\sigma_l^2}}{2}.$$

We substitute the values found earlier stress σ_l :

$$(11) \quad \sigma_\theta = \frac{1}{2} \sigma_s (\beta \cdot \mu(tg\alpha \cdot e^{f \cdot l} - g) \pm \sqrt{4 - 3\beta^2 \mu^2 (tg\alpha \cdot e^{f \cdot l} - g)^2}),$$

where

$$f(\alpha; \varphi; \Delta\rho; \rho) = \Phi(\rho; \alpha; \varphi) -$$

$$-\frac{1}{\Delta\rho tg\alpha} + \frac{l \sin(\alpha - \varphi)}{R \sin \alpha \sin \varphi}$$

$$\Phi(\rho; \alpha; \varphi) = \frac{\rho \cos \alpha \sin \varphi - \Delta\rho \sin(\alpha - \varphi)}{\rho \sin \alpha \sin \varphi}$$

$$g(\rho; \alpha; \varphi) = \frac{1}{\Phi(\rho; \alpha; \varphi)}$$

From constraint equations to the strain and stress, we obtain the analytical expressions for determining the linear relative deformation.

$$(12) \quad \varepsilon_\rho = -\frac{\sigma_s}{12G'} (3 \cdot \beta \cdot \mu(tg\alpha \cdot e^{f \cdot l} - g) \pm \sqrt{4 - 3\beta^2 \cdot \mu^2 (tg\alpha \cdot e^{f \cdot l} - g)^2})$$

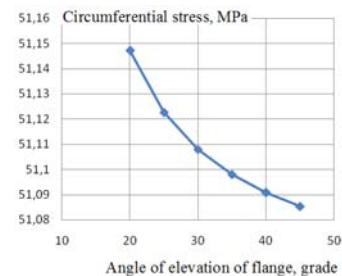
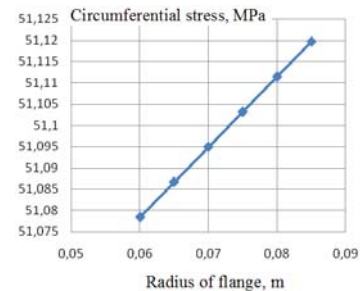
$$(13) \quad \varepsilon_\theta = \pm \frac{1}{6G'} \sigma_s \sqrt{4 - 3\beta^2 \cdot \mu^2 (tg\alpha \cdot e^{f \cdot l} - g)^2}.$$

$$(14) \quad \varepsilon_l = \frac{\sigma_s}{12G'} (3\beta \cdot \mu(tg\alpha \cdot e^{f \cdot l} - g) \mp \sqrt{4 - 3\beta^2 \mu^2 (tg\alpha \cdot e^{f \cdot l} - g)^2})$$

Calculation on the resulting mathematical model allowed to analyze the magnitude and nature of the effective stresses change during deformation of tube workpieces of copper M1. In Fig. 2 shows the change in the meridional stress σ_l and circumferential stress σ_θ depending on technological factors. The highest level of stress observed in the circumferential direction, and they are stretched.

The mathematical model to evaluate the state of stress components, has an axial symmetry is universal, because it involves an implicit function, this function describes a surface to be obtained by the expansion of pipe, in this case, the equation of a truncated cone.

Based on the analysis of these relations for linear strain we revealed their relationships to the technological parameters of uneven expansion of pipe.



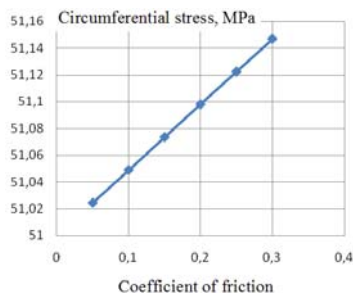


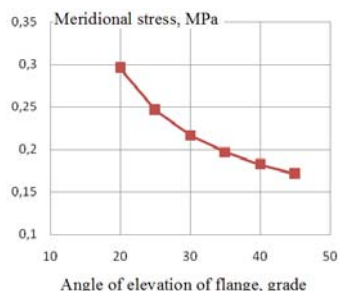
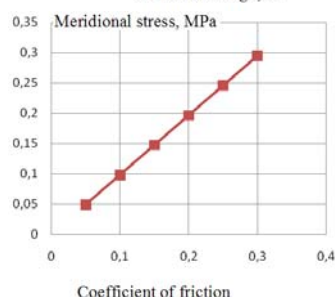
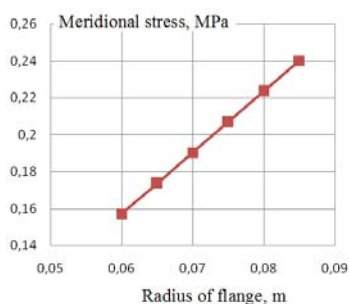
Fig. 2. Change meridional σ_1 and circumferential σ_θ stress depending on technological factors

RESUME

1. We have established the relationships between value and the nature of changes of the radial and circumferential stress to the terms of the friction on the contact surfaces, with the flange angles and forming a conical section, with other geometrical features, including thickness of the pipe workpiece wall changes. This makes it possible to refine the results analysis of stress is compared with existing methods.

2. Based on established relationships a mathematical model of expansion of pipe are developed, this model allows us to analyze the stress and strain state of the tube workpiece in the process of plastic deformation. Feature of the developed mathematical model of expansion of pipe of conical punch is calculation possibility of rotation axis of conical section and the original tube workpiece at a given angle γ , so the model has a wider range of applications and is universal enough.

3. The experiments showed that in the expansion of pipe stresses don't exceed the limit values for these materials and any defects during forming don't appear.



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