ANALYSIS OF THE DEEP DRAWING PROCESS OF BOX-SHAPED PARTS

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Abstract: *The analysis of stress-strain state of the bisector of the corner of the blank at a drawing of box-shaped parts. Analytical dependences for the meridional and circumferential stress on the bisector of the angle. It is shown that an increase in the limit drawing ratio compared with an extract of the cylindrical part is a consequence of the growth in absolute value of district compressive stresses. It was found that the maximum value of the coefficient of drawing of box-shaped parts cannot exceed the value of -* $K = \exp\left(1 + 1/\sqrt{3}\right) \approx 4{,}84$.

KEYWORDS: DRAWING; BISECTOR; STRESS; STRAIN.

1. Introduction.

One of the difficult problems in the theory of forming sheet metal drawing process is the analysis of box-shaped parts**.** In this case, the difficulties characteristic in the analysis of drawing process of cylindrical parts, added further difficulties related to the need to consider the variability of the strain distribution along the perimeter of products, due to the absence of axial symmetry in the plastic region [1]. When developing of technological processes drawing box-shaped parts for easy implementation of practical calculations we introduce the concept of conditional drawing coefficient, which is similar to the drawing ratio of cylindrical parts, is determined by the expression $K = R/r$, where r –a radius of curvature in the plane mates of box-shaped parts wall, R - distance from the center to the edge of the corner rounding of blank the bisector of angle[2].

Many experimental studies have established that at multistage low draw box-shaped parts with a relatively large radius of corner rounding, the limiting ratio of drawing of corner region is 1.5-2 times higher than the drawing of cylindrical parts[1,2].

In order to explain of this experimental fact and clarify the mechanism of forming of the sheet metal in a non-axe symmetric drawing Popov E.A. developed an approximate theory analysis of stress-strain state in the absence of axial symmetry of deformation [1]. In this theory, the following main assumptions: the analysis carried out without changing the thickness and deformation hardening, introduced a priori given expression for the shear stress is linearly dependent on the circumferential coordinates. Under that conditions the use of assumptions plasticity hypothesis on the constancy of maximum shear stress (a condition Tresca-Saint Venant), allowed reduce the problem to a statically determinate and obtain analytical dependence for distribution of stresses along the meridional contour holes of the matrix. From this solution it follows that the greatest value of the specified stress on the front edge of the matrix along the bisector of the corner region of the blank different from the analogous values for the ax symmetric drawing some factor less than one, depending on the circumferential extension of the plastic zone.

By equating established in such a way that the greatest value of the meridional stress with yield strength of the material $\left(\sigma_{\rho\max}/\sigma_s = \left(1 - a/2\alpha\right)\cdot\ln\left(R/r\right) = 1;\quad a = 0{,}5; \alpha = \pi/4\right)$, it is theoretically possible determine the drawing ratio $K = R/r = \exp\left(1/0{,}682\right) \approx 4{,}3$ [1]. Other similar analytical solutions [3 and etc.] differ from slightly above and only specify the value of a factor in the expression for the maximum meridian stress.

In [1,2] the increase in the limiting factor in the drawing box-shaped parts based on the fact that, "… on the boundaries of the corner region of the shear stresses are applied, oriented towards the center of curvature and create strength, pulling corner portion of the hole matrix and unloading dangerous in this section, and it also decreases the meridional tensile stresses".

Such a justification to increase the limiting ratio in the drawing of box-shaped parts causes a certain confusion for the following reasons: it is well known that shear stresses can not create power. In this problem the shear stresses in the corner region of the blank produce moments about the axis perpendicular to the plane of the sheet. The direction of the bisector of the corner portion of the blank on the condition of symmetry is the main focus, so in this respect can not occur shear stresses, therefore, does not exist shear stresses can not decrease the meridional tensile stresses and unload the dangerous section.

In [3] an increase in the drawing ratio and increasing the height of the corner of the box-shaped parts is justified on the basis of even more unbelievable assumptions "... the difference between the velocities of the material in the walls of the straight and corner sections. Therefore, the condition of the continuity of blank to be that fast moving items seized slowly moving adjacent elements and have them pushed into the matrix and unloaded stress impact". Obviously, such statements need no comment.

It follows that in the present time in the scientific technical literature there are no reasonable analytical solutions to determine the limiting ratio in the drawing box-shaped parts. It therefore seems appropriate mathematically correct statement of problem of forming of sheet metal in the absence of axial symmetry of the plastic region, on the basis of which it will become possible to determine the ultimate value of the drawing ratio and study of the mechanism of forming, set free from contradictions.

2. Problem statement and analysis of the stress state.

Consider forming in the corner region of the blank in the drawing box-shaped parts, considering that forming the sheet metal occurs in plane stress conditions [1,2]. It is assumed that the plate thickness S is small compared with the transverse dimensions of the parts, whereby it is considered that the stress components acting on the middle surface, little change in thickness. For this reason, these stress values are averaged over the thickness of the respective stress components. From the condition of symmetry of the plastic zone at the corner of blank should be that the direction of the bisector is the main focus, so that the meridional and circumferential stresses acting in this direction are the main normal stresses. Therefore, for analysis of stress-strain state of the bisector is permissible to use the results of the analytical solutions obtained for axis symmetric drawing.

In [4-7] demonstrated and justified that the main directions of stress-strain state is appropriate and convenient to consider the deviatory plane of Mises plasticity cylinder in oblique two-dimensional coordinate system. In these works, the original equations of the theory of plastic flow in the plane stress, namely, the equilibrium equation for the changes in the thickness of the material plasticity condition Mises condition of constant volume constraint equation stress and increment (speed) strains are reduced to a single structure in the form of a differential relationship between meridional stress increments and equivalent deformation (strain intensity)

$$d\sigma_\rho = \sigma_s d\varepsilon_i \ . \qquad (1)$$

Received of (1) the following according to the meridional and circumferential stress

$$\sigma_\rho = \sigma_s \frac{2}{\sqrt{3}}\cos\left(\varphi + \frac{\pi}{6}\right);\quad \sigma_\theta = -\sigma_s \frac{2}{\sqrt{3}}\sin\varphi, \qquad (2)$$

obtained from the combined solution of the equations of stress and relationship increments (speeds) strains based on the constancy of the volume and satisfying plasticity at plane stress[1]

$$\sigma_\rho^2 - \sigma_\rho\sigma_\theta + \sigma_\theta^2 = \sigma_s^2. \qquad (3)$$

The receipt of power-law of strain hardening $\sigma_s = A\varepsilon_i^n$ ($A = \sigma_b e^n n^{-n}$, $n = \ln(1+\delta)$ - parameters receipted law of strain hardening, σ_b - tensile strength, and δ - relatively uniform deformation of the material when tested in uniaxial tension) under the assumption of proportional changes in the components of linear strains $(\varepsilon_\rho/\varepsilon_\theta = const)$, allowed to integrate a predetermined differential equation and obtain analytical dependence for the equivalent strains

$$|\vec{\varepsilon}|_i = \varepsilon_i = (1+n)\frac{2}{\sqrt{3}}\cos\left(\varphi + \frac{\pi}{6}\right), \qquad (4)$$

where φ - the polar angle between the radial deformation and vector of equivalent strain in the deviator plane. Distribution of principal strains for the initial stage of the drawing, and a geometric interpretation of the nature and physical parameter φ considered in detail in [5].

One possible and theoretically founded explanations for this increase in the limiting drawing ratio of box-shaped parts is the assumption about the growth of the district compressive stresses along the bisector on the peripheral region of the blank.

In (3) that the circumferential stresses the absolute value may increase, while the growth of the absolute value of the meridional of stress. In order to substantiate the proposal will consider the initial stage of axe symmetric drawing $(\sigma_s = \sigma_{0,2};\, \varepsilon_i = 0{,}2\%;\, n = 0)$ in the direction of the bisector. In [5], in this case the relationship between the parameter set in the deviator plane and the relative coordinates ρ/r of the element in a material medium deformable blank in the form of relation

$$\frac{\rho}{r} = \exp\left[1 - \frac{2}{\sqrt{3}}\cos\left(\varphi + \frac{\pi}{6}\right)\right]. \qquad (5)$$

From (2) and (5) it follows that, $\varphi = \pi/3;\, \sigma_\rho = 0;\, \sigma_\theta = -\sigma_s$, $\rho/r_0 \Rightarrow e(2{,}72)$. Therefore, a further increase in the relations ρ/r is only possible in the transition of opposite $(\sigma_\rho\sigma_\theta \le 0;\, \sigma_\rho \ge 0;\quad \sigma_\theta \le 0)$ biaxial stress state of same name in the biaxial $(\sigma_\rho\sigma_\theta \ge 0;\quad \sigma_\rho \le 0;\quad \sigma_\theta \le 0)$. According to (2) in $\varphi > \pi/3$ the meridional stress changes sign and the main stress in absolute value reach the maximum possible, in a plane stress, values -$|2/\sqrt{3}|\sigma_s$ and $|1/\sqrt{3}|\sigma_s$. Comparing (5), and the like according to [1.2], you can see their formal external similarity. If the parameter φ in (5), characterized in the direction of the bisector (in the main direction) angular extent of stress-strain state in the deviator plane, then θ in [1,2] is a circumferential coordinate of the element in a material medium blank. Assuming in (5), we find

$$K = \frac{R}{r} \Rightarrow \exp\left(1 + \frac{1}{\sqrt{3}}\right) \approx 4{,}84. \qquad (6)$$

Thus theoretically possible the drawing ratio of box- shaped parts can not exceed 4.84.

If we assume that were not included in the analysis of factors (bending and straightening of curved edges on the deforming tools, friction, etc.) have the same effect on the decrease the theoretically possible factor in the drawing of cylindrical parts and box-shaped parts $(2{,}72 \Rightarrow 2{,}0 \div 2{,}1)$, practically achievable values in the second case it is sufficient close agreement with the experimental results $(4{,}84 \Rightarrow 3{,}5 \div 3{,}7)$ [1,2].

3. Results of the analysis and discussion. From the analysis it follows that the parameter φ of the bisector of the corner region of the blank at the box-shaped drawn on the details of the deviatory plane can vary $0 \le \varphi \le \pi/2$ and be engaged in the sector with a central angle equal равным $\pi/2$. In this range of the parameter φ vector of equivalent strain is either parallel or perpendicular to the oblique coordinate axes, whereby the main strains in the meridional and circumferential directions vary from 0 to 1. With large size of the plastic zone in the deviatory plane are realized following the scheme of the stress-strain states:

when $\varphi = 0$, ε_ρ positive, but ε_θ and ε_z – are negative and equal to $\varepsilon_\rho/2$, i.e., linear stretching deformation is realized;

when $\varphi = \pi/6$, $\varepsilon_z = 0$ but ε_ρ and ε_θ, are equal in value and opposite in sign, i.e., realized a net shift (plane strain) in the plane $(\rho;\theta)$;

when $\varphi = \pi/3$, ε_θ negative and positive, but ε_ρ and ε_z numerically equal $\varepsilon_\theta/2$, i.e., linear compressive strain is realized;

when $\varphi = \pi/2$, $\varepsilon_\rho = 0$ but ε_θ and ε_z are equal in value and opposite in sign, i.e., is realized a net shift (plane strain) in the plane $(\theta;z)$.

Therefore, in general, on the bisector of the corner of the blank at a drawing box-shaped parts, plastic region is displayed on the deviatory plane strains in three specific sectors with the central angles equal $\varphi = \pi/6$, on the borders of which are changing the scheme of the stress-strain states.

The results of the analysis of the relationship between the value and character of the distribution of shear stresses and the growth of the district compressive stresses will be presented in our future publications.

3. Conclusions

1. The analysis of the stress-strain state in the drawing of box-shaped parts based on an interdependent changing the thickness of the material and strain hardening.
2. On the basis of the established distribution of the meridional and circumferential stresses in the direction of the bisector of the angle defined theoretically possible ratio of drawing box-shaped parts $K = \exp\left(1 + 1/\sqrt{3}\right) \approx 4{,}84$.

3. The mechanism of forming non axially symmetric drawing, allows to justify an increase in the limiting ratio compared to the drawing of cylindrical parts.

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