CONSIDERATIONS REGARDING THE EXTENSION BENDING OF WIDE BANDS ON DOUBLE CONVEX SURFACES

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Abstract: *The paper presents an analysis of the processing by cold bending of wide strips on double convex surfaces. The state of tension and deformation are plane states. The deformation state is defined by two real and opposite main deformations. It was established calculus formulas for the real principal deformations at a point on the workpiece, for thickness and for stretch force in the different piece sections, whose can be utilised in technological calculus.*

Keywords: *bending, cold deformation, sheet metal, stress.*

1. Introduction

Some parts obtained by bending from thin sheet metal have a defined geometric shape of relatively large radius of curvature in its sections and therefore, in most cases, cannot be obtained by ordinary bending. This is due to the bending radius of the part which cause small deformations of the material, largely being elastic deformations. In order to make such parts, it is necessary to apply the stretch bending process. The tensile force creates elongation deformations that overlap with the bending ones, resulting in the end remaining plastic deformations that determine the obtaining of the geometric shape of the piece (figure 1). By applying a tensile force, the radius of curvature of the neutral fiber moves with a certain distance x to the center of curvature on the bent part [4].

Sheet metal semi-finished products for which two of their dimensions are much larger than the thickness, when cold plastic deformation is characterized by stress and deformation states characteristic of membrane deformation.

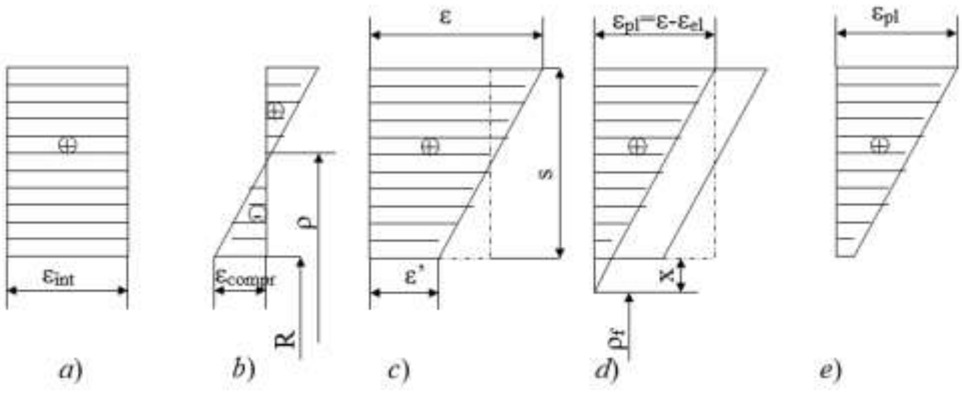

Figure 1 *Deformation bending deformation scheme.*
a-deformations for stretching; b- deformations for bending; c- overlapping the deformations from the tension over the bending ones d- overlapping the elastic deformations at the discharge; e- the remaining residual deformations

For membranes, due to the very small thickness compared to the other dimensions, the stress state is a plane state characterized by two main normal stresses σ_1 and σ_2 and also a spatial deformation state with the real main deformations ε_1, ε_2 and ε_3 between which there is the relation [1], [3]:

$$\varepsilon_1 + \varepsilon_2 + \varepsilon_3 = 0 \qquad (1)$$

When bending with tension on a cylindrical surface, the semi-finished products in the form of wide strips practically do not change their width and therefore the real main deformation ε_2 is zero [2]. In this case corresponding to relation (1) it results:

$$\varepsilon_1 = -\varepsilon_3 \qquad (2)$$

Considering the state of deformation and the constancy of the volume, the intensity of the deformation at a certain point on the band subjected to deformation by stretch bending will have the value determined by the relation [3]:

$$\varepsilon_i = \frac{2}{\sqrt{3}}\varepsilon_1 \qquad (3)$$

2. ANALYSIS OF BENDING WITH A DOUBLE CONVEX SURFACE

For bending with tension on punches with surfaces with two radii of curvature in two perpendicular sections, the semi-finished product in order to be able to deform properly is necessary to be processed in a previous operation in the form of a cylindrical membrane (figure 2).

Further, the analysis of the deformation state of the material will be done for two cases, as follows: when the cylindrical surface has additions on the edge of the cylindrical profile with flat shape and when the processing additive is cylindrical on both sides, following the profile of the cylindrical membrane.

If the semi-finished part bent cylindrically previously with radius ρ_φ has additions of flat-shaped material on either side, they contribute depending on the size to the displacement of the neutral fiber of the deformations towards the *GG* line of the membrane profile (figure 3).

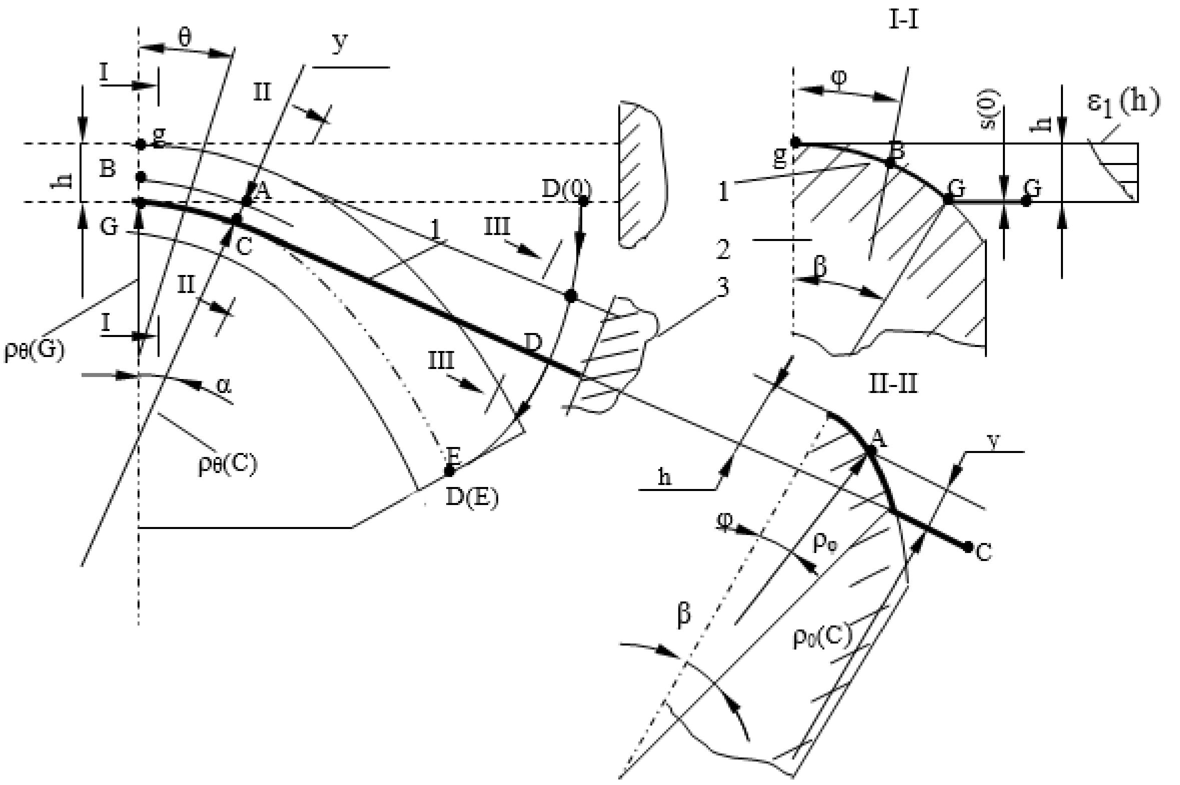

Figure 2. *Diagram of the extension of the wide strips on the punch with biconvex surface 1-semi-finished; 2-punch; 3-clamping device*

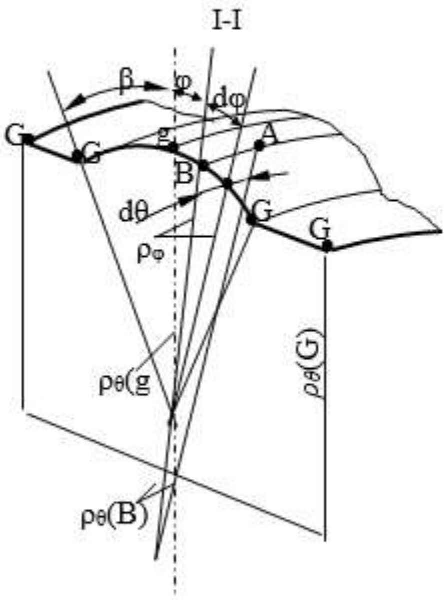

Figure 3. *Section in a double piece curve*

By bending on the profiled punch with different radii in two perpendicular sections, the *GgG* portion of the blank *1* is transformed into a double curved surface, and the flat *GG* portion into a cylindrical surface, whose direction is the *GE* line.

The effective realization of the piece is obtained by wrapping the semi-finished product on the surface of the punch. This winding is carried out by means of the device for gripping the semi-finished product which moves relative to the punch. The material point *D* on the blank, which is close to the mounting brackets of the blank, moves on the evolution *D(0)E*, so that the lengths *GD (0)* and *GE* are equal. Due to the additions of material, the calculation of the tensile deformations that occur in the material of the semi-finished product that forms the cylindrical surface and are perpendicular to the section *I-I*, when bending with radius ρ_θ is simple (fig.2).

Thus, it can be easily deduced that the value of the real principal deformation $\varepsilon_1(\theta)$ is defined by the relation:

$$\varepsilon_1 = \ln(1+\frac{y}{\rho_\theta}) \qquad (4)$$

and constant along the wrapped part if the radius ρ_θ is constant. For a given punch area, the y coordinate can be determined from geometric conditions depending on the radius of curvature ρ_φ of the normal profile of the tool, the angle φ made by the radius on which there is a certain point A with the profile axis and the angle of the semi-profile β, with the relation:

$$y = \rho_\varphi(\cos\varphi - \cos\beta) \qquad (5)$$

The deformations ε_1 on the *GG* area of the profile is in the elastic range and have relatively small values because in the vicinity of this area the neutral fiber of the profile section must pass.

The thickness of the membrane along the segment *gG* can be established from the condition of constancy of the volume of deformed material, with the relation:

$$s = \frac{s(0)}{1+\dfrac{y}{\rho_\theta}} \qquad (6)$$

and the segment *GG*, $s = s(0)$.

The calculation method described for the deformation of the semi-finished product is valid only for semi-finished products for which the gG / GG ratios of the profile segments satisfy the condition that the stresses produced in section II-II do not reach the flow limit, ie:

$$\frac{F}{A_0} \lhd \sigma_c \qquad (7)$$

wherein the tensile force *F* of the cylindrical rib of the profile is determined by the relation [2]:

$$F = \int_0^\beta \frac{4}{\sqrt{3}} K s_0 (\frac{2}{\sqrt{3}}\varepsilon_1)^n e^{-\varepsilon_1} \rho_\varphi d\varphi \qquad (8)$$

And A_0 is the area of section III-III, σ_c is the flow voltage of the semi-finished material.

Condition (7) expresses the possibility of deformation of the membrane on the cylindrical profiled area, without the material on the GG segments deforming plastically, because the neutral fiber passes through their vicinity.

If the profile section of the finished part has *GG* segments of small or close to zero dimensions, in order to satisfy the inequality

(7), additions of material for technological purposes of appropriate values are introduced, which are cut after processing.

When the size of the *GG* segment is zero, the addition can be taken in the extension of the gG segment. In this case, when wrapping the semi-finished product on the tool, the evolution *D (0) E* is defined by the length of the fiber on the edge of the profile before the technological addition is made to the finished part.

In this case, when bending the semi-finished product, the main deformation ε_1 and the main stress σ_1 for the material layers on the convex side of the *GE* curve are tensile, and for the concave parts they are negative. As a result, the processing addition loses its stability and curls.

If the inequality (7) is not met, then the plastic deformation of the whole blank is required by stressing with an additional axial tensile force. This requires another movement trajectory of the gripper, which must at the forward end of the travel to reach the plane of symmetry II, then when it would have the involute path *D (0) E*.

At any time during the process, the deformation ε_1 on the *CD* portion of the blank is evenly distributed, and on the *GC* portion unevenly, due to the friction action between the blank and the deformation tool as well as the way the blank deforms

The deformation ε_1 has the highest values for the fibers having the coordinates $y = h$, in which case the relation (4) becomes:

$$\varepsilon_1 = \varepsilon_1(h) = \ln(1 + h/\rho_\theta) \qquad (9)$$

The value $\varepsilon_1(h)$ on the fiber most required for stretching may not exceed a certain value ε_{1lim} which must be less than the breaking point of the material so that cracks do not appear on the surface of the part.

The connection between the forces acting on the blank in two sections, for approximate technological calculations, can be established considering the influence of friction on the forces at the ends of a strip wrapped on a profile. Thus, the relation that expresses the connection between the force in section II-II and the force in a current section that forms the angle θ: with section II has the form [5]:

$$F(\theta) = F(C)e^{-\mu_K(\alpha-\theta)} \qquad (10)$$

In this relation $\mu_K = K_\mu \mu$, where K_μ is a coefficient that reflects the influence of the curve $1/\rho_\varphi$ on the contact pressure between the blank and the tool, so on the friction force, and μ is the coefficient of friction between the blank and the tool. Taking into account the relation (8) and the connection between stresses and deformations in the plastic field [2], the forces acting in the two sections are defined by the relations:

$$F(\theta) = \int_0^\beta \frac{4}{\sqrt{3}} K s_0 [\frac{2}{\sqrt{3}}\varepsilon_1(\theta,\phi)]^n e^{-\varepsilon_1(\theta,\phi)} \rho_\phi d\phi + \frac{4}{\sqrt{3}} K s_0 L_G [\frac{2}{\sqrt{3}}\varepsilon_1(\theta,\beta)]^n e^{-\varepsilon_1(\theta,\beta)} \qquad (11)$$

$$F(C) = \frac{4}{\sqrt{3}} K s_0 L(0)[\frac{2}{\sqrt{3}}\varepsilon_1(C)]^n e^{-\varepsilon_1(c)} \qquad (12)$$

Where in $L_G = GG$; $L(0) = gGG$ (fig. 3)

Replacing relations (11) and (12) in relation (10) it follows that the deformation $\varepsilon_1(C)$ which is related to the deformation $\varepsilon_1(\theta, \beta)$ by the following expression:

$$\int_0^\beta [\frac{2}{\sqrt{3}}\varepsilon_1(\theta,\varphi)]^n e^{-\varepsilon_1(\theta,\varphi)} \rho_\varphi d\varphi + \frac{L_G[\frac{2}{\sqrt{3}}\varepsilon_1(\theta,\beta)]^n}{e^{\varepsilon_1(\theta,\beta)}} = \frac{L(0)[\frac{2}{\sqrt{3}}\varepsilon_1(C)]^n}{e^{\mu_K(\alpha-\theta)+\varepsilon_1(C)}} \qquad (13)$$

For machining parts in the case of tension bending with double convex surfaces that have angles α and β with small values, usually below $10°$ - $15°$, with relatively large radii of curvature, the sequence of deformation of the blank is represented in Figure 4.

Profiled cylindrically above, the strip 1 is fixed in the clamping device 3. The construction of the device can be made so as to be able to bend the strip which previously had a flat shape and then tighten for fixing (figure 4, *a*).

For winding the membrane on the die 2, each clamping device as it is moved relative to the involute *D (0) E*. The trajectory of the movement of the gripping device can be another curve to the point *D* goes closer to the plane of symmetry of the die than in the case of the involute *D(0)E,* but has the same end point E.

Thus, during this movement, the membrane with the initial cylindrical shape can take on a much more complex shape, depending on the elastic or elasto-plastic character of the deformations of the material. The semi - finished areas arranged on either side of the *gE* line is corrugated (fig.4, *b)*. For this reason, after the winding movement, the stretching movement is required (fig.4, *c)*. The movement path II *D* is usually right *D(1)D(2)* intersecting the curve *gE* point *E.*

The connection between the forces and deformations in section III-III and the section forming the angle θ with section I-I can be obtained from the relations (11) and (12) for which $L_G=0$ is adopted.

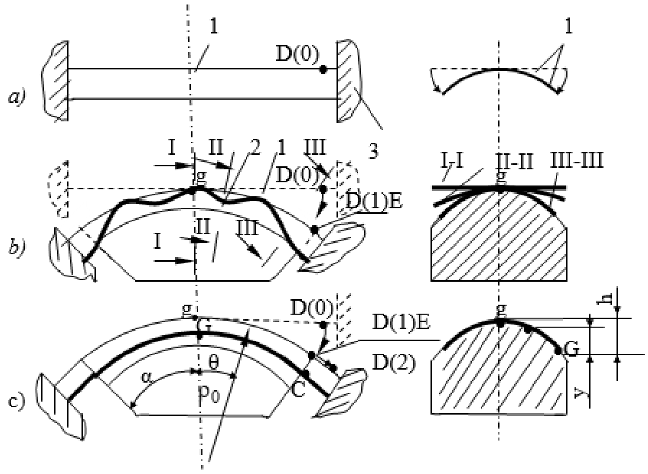

Figure 4. *Succession of bending with tension on biconvex surfaces*
1- semi-finished; 2- punches.3- fixing device

The areas of maximum adhesion of the membrane to the surface of the punch are in the marginal sections passing through point C, and then gradually they extend to the section that determines the plane of symmetry of the punch. The maximum adhesion of the membrane to the punch in the plane of symmetry takes place when in this section the distribution of the deformation ε_1 fulfills the relation (4). A part with certain dimensions can be obtained by bending with tension only if the deformation due to the limit stretch in point *g* is greater than the deformation $\varepsilon_1(h)$ in point *g* of the given surface (fig.4, *c)*, determined with the relation (4) so as not to result in the crease on the marginal areas of the profile.

Bending with stretching can be done with special construction molds or on special stretching machines.

3. CONCLUSIONS

Analysis of the stress and deformation with tensile bending blanks wide strip double convex surfaces emphasizes that this is a flat state of stress and strain. Deformation state is defined by two equal real principal deformations and of opposite sign.

Calculation relations have been established for the real main deformations, for the calculation of the thickness of the deformed part as well as for the forces from different sections of the strip with which the technological calculations can be performed when bending the strips on double convex surfaces.

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