THEORETICAL CONSIDERATIONS AT CYLINDRICAL DRAWING AND FLANGING OUTSIDE OF EDGE ON THE DEFORMATION STATES

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Abstract. This paper presents an analysis of the deformation states by drawing and flanging outside of edge, in order to determine of the limit between processes depending on the degree of deformity.
Analytical relationships were determined to calculate the main real deformations, relative height increase of drawing pieces walls due to radial real deformations by drawing coefficient.
Relations were established without considering friction between blankholder, female die and bending radius of workpiece material on the female die. Analysis showed that the drawing coefficients of between *0.5-0.8* the processing can be considered drawing and when is greater than *0.8*, relative height increases due by radial deformation is insignificant, processing can be considered as outside flanging of edge processes.

Keywords: *drawing, deformation, drawing coefficient, relative height, outside flanging of edge.*

1. Introduction

Drawing of a sheet metal is a process that consists in a plastic deformation processing of a plan workpiece in a hollow, or reducing the size of a cross section of hollow piece to increase the depth [1].

During processing by drawing, workpiece flange reduce their dimensions in plan as part cavity is formed under the action of deformation force *F* (fig1.).

If the plan workpiece is related to a cylindrical coordinate axis ρ, θ and *z*, at any point *M* of flange acting plastic deformation stress of the flange, σ_ρ and σ_θ, which are the main normal stress and are definite by relations, [1]:

$$\sigma_\rho = \sigma_c \, ln\frac{R}{\rho}; \; \sigma_\theta = -\sigma_c\left(1 - ln\frac{R}{\rho}\right) \qquad (1)$$

where: σ_c is the yield strength of the blank material; *R*- workpiece radius; ρ – point radius, M.

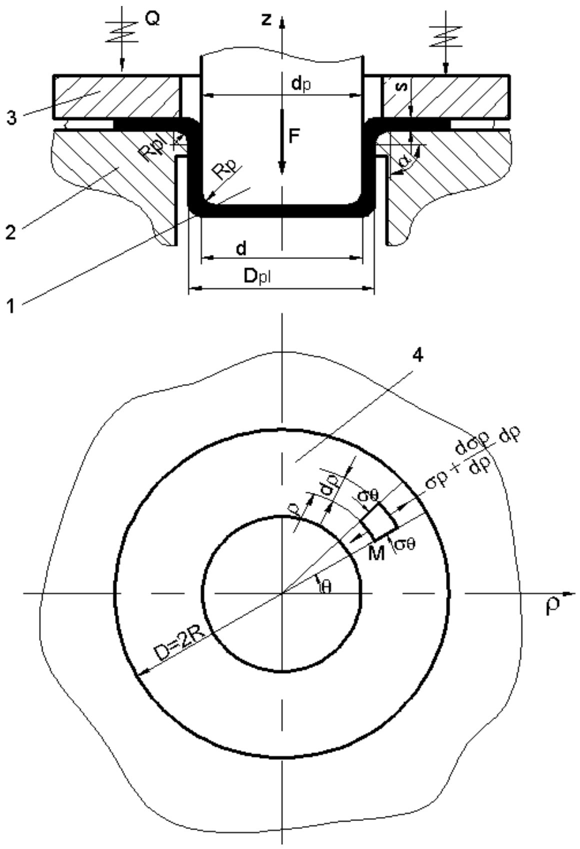

Figure 1. *Cylindrical drawing scheme*
1- punch; 2- female die; 3- blankholder; 4- blank

Principal normal stress in the z direction, σ_z, is insignificant in value compared with σ_ρ and σ_θ, due to the small value of the thickness blank relative to other dimensions of the blank and the low value of the stress generated by the blank holder force Q.

Thus it can be considered that the tension state of the work-piece flange may be considered a plan stress state. The total drawing stress arising in the walls, $\sigma_{\rho t}$, is greater than σ_ρ, due to the friction that occurs between the workpiece and mould elements, and the stress required at the bending and straightening of the drawing of metal sheet.

The calculation of $\sigma_{\rho t}$ is [1]:

$$\sigma_{\rho t} = \left\{ \sigma_c \ln\frac{R}{r} + \mu p \left[\frac{D^2 - \left(d + 2R_{pl} + s\right)^2}{2sd} \right] \right\} e^{\mu\alpha} + \frac{\sigma_c}{2\frac{R_{pl}}{s} + 1} \quad (2)$$

where: r is radius measured average fiber thickness of workpiece;
p - pressure generated by force Q on the flange workpiece by blankholder;
μ - coefficient of friction between the workpiece material and the mould elements;
R_{pl} - rounding radius of the female die;
s- thickness of the blank;
α - angle corresponding arc with R_{pl} radius.

The $\sigma_{\rho t}$ value defined by the relation (2) can be drawing maximum force F, calculated:

$$F = \pi d s \sigma_{\rho t} \quad (3)$$

2. Deformation state analyze of workpiece

If a point M of the workpiece flange the stress state created the by the force F can be considered as approximately a flat stress state, the deformation state is a space deformation state due to the special deformation condition. In all three directions, ρ, θ and z are produced the real main strain ε_ρ, ε_θ and ε_z (fig. 2).

The analyse of deformation state will be made without considering friction between blankholder, female die and bending radius of workpiece material on the female die.

The value of circumferential strain ε_θ in certain M point, on workpiece flange located at the radius ρ, when it reaches on the wall with the average radius r pressed in position M, is defined by the relation [2]:

$$\varepsilon_\theta = \ln\frac{r}{\rho} \quad (4)$$

If we take into account only the main normal stresses that cause plastic deformation of the flange connection between the principal stress and real strains in plastic domain, is defined by the relation [3, 4]:

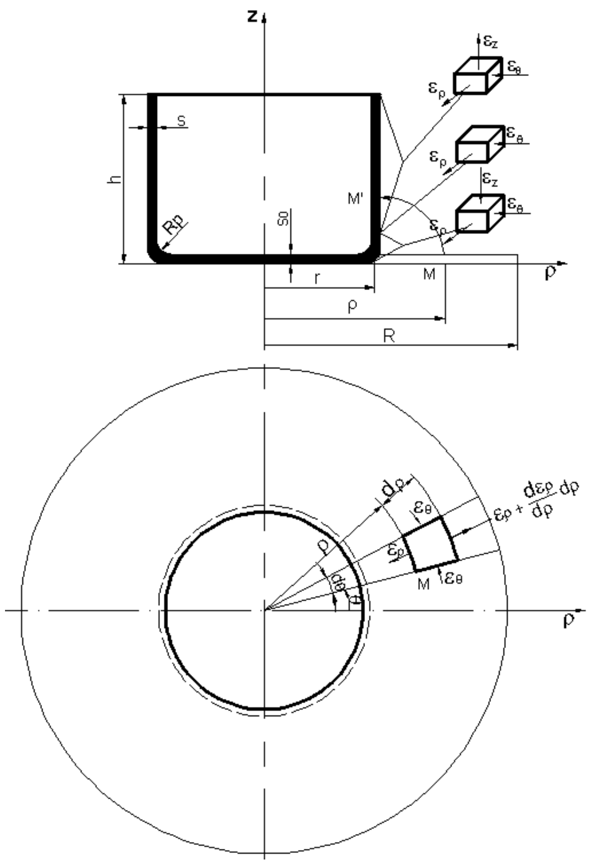

Figure 2. *Deformation state at cylindrical drawing*

$$\frac{\sigma_\rho - \sigma_\theta}{\varepsilon_\rho - \varepsilon_\theta} = \frac{\sigma_\theta - \sigma_z}{\varepsilon_\theta - \varepsilon_z} = \frac{\sigma_z - \sigma_\rho}{\varepsilon_z - \varepsilon_\rho} = \text{ct} \quad (5)$$

Because it believes that $\sigma_z \approx 0$, the relation (5) becomes:

$$\frac{\sigma_\rho-\sigma_\theta}{\varepsilon_\rho-\varepsilon_\theta}=\frac{\sigma_\theta}{\varepsilon_\theta-\varepsilon_z}=\frac{\sigma_\rho}{\varepsilon_\rho-\varepsilon_z} \tag{6}$$

According to the law of constancy of volume in plastic deformation at any point, in the volume of work-piece material relationship can be written:

$$\varepsilon_\rho+\varepsilon_\theta+\varepsilon_z=0 \tag{7}$$

System defined by equations (5), (6) and (7), and taking into account relations (1) follows:

$$\varepsilon_z=\frac{ln\frac{r}{\rho}\left(2\,ln\frac{R}{\rho}-1\right)}{2-ln\frac{R}{\rho}} \tag{8}$$

$$\varepsilon_\rho=\frac{\ln\frac{r}{\rho}\left(1+\ln\frac{R}{\rho}\right)}{\ln\frac{R}{\rho}-2} \tag{9}$$

The graphical representation of the real main strains ε_ρ, ε_θ and ε_z based on the position of the point M in the plane workpiece is shown in figure 3.

3. Calculating thickness and height relative growth of wall piece

Analysis of the real main strains graph ε_z along radius ρ, according to the current point shows a thinning of the wall part at proximity to the bottom part, with negative values, then pass through a point that has the value zero , after which shows a thickener to the top surface, it has positive values.

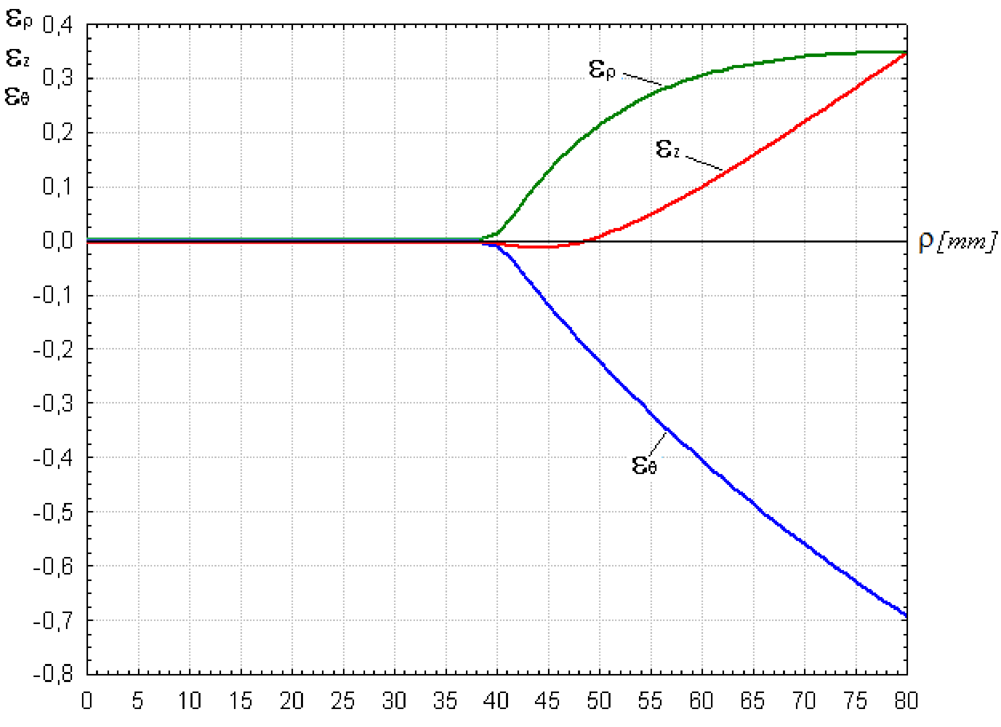

Figure 3. *Graphical presentation of the real main strains along radius ρ of point M position*

The real main strain ε_z is defined by the equation [2]:

$$\varepsilon_z=ln\frac{s}{s_0} \tag{10}$$

where s_0 is the thickness of the plane workpiece at a point M located on the radius ρ and s is the wall thickness at point M' located at the radius r (fig. 2).

Taking into account by the relation (8) and equation (10) by calculus the relationship of the wall thickness drawing piece is determined at a current point *M*, on the plane work-piece with s_0 thickness and ρ radius located, with the following relation:

$$s = s_0 e^{\frac{ln\frac{r}{\rho}\left(2\,ln\frac{R}{\rho}-1\right)}{2-ln\frac{R}{\rho}}} \tag{11}$$

Equation (11) shows that the thickness of the workpiece does not change if:

$$2\,ln\frac{R}{\rho}-1=0\text{ , or }\quad ln\frac{R}{\rho}=\frac{1}{2}$$

from the resulting relationship known:

$$\rho \approx 0.60653\ R \tag{12}$$

It is easily seen from equation (12) that the positions of points with radius values of ρ lower than those determined by the relation (12) has been a thinning of the walls, and above this value is a thickening.

Thickening is maximum at the position points $\rho = R$. For this position of the point *M*, by equalizing the relationship (8) with (10) results:

$$ln\frac{s}{s_0}=ln\left(\frac{R}{r}\right)^{\frac{1}{2}} \tag{13}$$

If noted by *m* the report *r/R*, report entitled drawing coefficient, can be obtained thickness of the top wall defined by the relation:

$$s=\frac{s_0}{\sqrt{m}} \tag{14}$$

If we consider the limit values of drawing coefficient as *0.55* to *0.8*, for the lower limit and upper limit, using equation (14) gives a *29 %* thickening wall piece respectively *11.8%*.

For flange flat blank area to get to the cylindrical wall of piece, it is necessary compression with real main circumferential strain ε_θ. Simultaneously, the material of flange flows to radial direction because is stretched with real main radial strain, ε_ρ.

Therefore height of the piece *h* will be greater than *(D-d)/2*. Increasing the height Δh because the radial extent can be determined from the relationship:

$$\varepsilon_\rho=\frac{\Delta d\rho}{d\rho}\text{ or }\Delta d\rho=\varepsilon_\rho\, d\rho \tag{15}$$

where ε_ρ is defined by relation (9).

By integration of relation (15) between *r-R* resulting increase height Δh of the size in the radial direction defined by the relation:

$$\Delta h=\int_r^R \varepsilon_\rho d\rho \tag{16}$$

To solve the integral (16) is developed in series of function ε_ρ around *0* value, using Mac Laurin formula [5], retaining the first two terms of development and it get:

$$\varepsilon_\rho \approx \frac{r}{\rho}+\frac{3r-R}{R-3\rho} \tag{17}$$

By substituting ε_ρ defined by equation (17) into (16) and performing calculations follows:

$$\Delta h = r\,ln\frac{R}{r}+\left(\frac{1}{3}R-r\right)ln\frac{2R}{3r-R} \tag{18}$$

Equation (18) can be expressed in relative values written in the forms:

$$\frac{\Delta h}{R}=m\,ln\frac{1}{m}+\left(\frac{1}{3}-m\right)ln\frac{2}{3m-1} \tag{19}$$

or:

$$\frac{\Delta h}{r}=ln\frac{1}{m}+\left(\frac{1}{3m}-1\right)ln\frac{2}{3m-1} \tag{20}$$

Graphic representation of the relative height according to the coefficient of drawing is shown the increase $\Delta h/R$ and $\Delta h/r$ according to decrease of drawing coefficient and is shown in figure 4.

It can be easily seen that along decreases of drawing coefficient takes place the growth of the relative height.

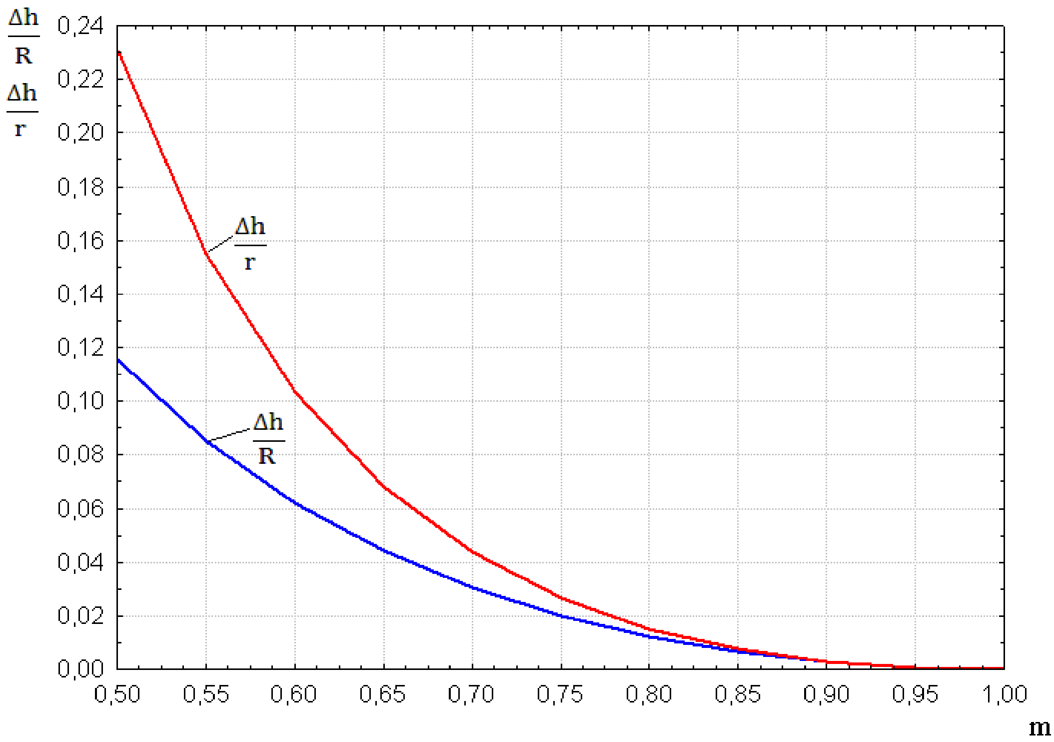

Figure 4. *Graph of relative height growth of piece along drawing coefficient.*

This is explained by the growth of real main radial strain ε_ρ with decreasing drawing coefficient because the material volume in the flange zone reaches in wall drawing piece is greater.

4. Deformation state at flanging outside of edge

Processing the flanging outer edges of pieces with a convex shape is characterized by a stress and strain state similar to the shallow drawing, without holding [2].

In this process the volume of material displaced from the flange obtained by the reflection in the wall of the blank is less than the case of piece formed by drawing with high degrees of deformation, and due to this cause the real main strains ε_ρ, ε_θ and ε_z are smaller.

Literature does not clearly specify the reasons not to that degree of deformation of the work-piece can be considered the outside flanging of edge and where it can be seen by drawing processing.

Analyzing of graphs shows that relative height growth piece ($\Delta h/\ R$ and $\Delta h/\ r$) is produced at drawing coefficients with small value is determined.

Thus corresponding relations (18) and (19) for $m = 0.8$ result $\Delta h/R = 0.012$ and $\Delta h/r = 0.015$.

This shows that the elongation of the material in the radial direction is very small compared to the size of the work-piece dimension or piece.

It can be said that if the plan workpiece dimensions processing by flanging outside of edge is determined by calculating the average fibber length, piece height deviations are quite small for great values of drawing coefficient.

Therefore it can be considered for drawing coefficient greater than 0.8, because lengthening in radial direction is between the dimensional allowances provided for tolerance of the free dimensions obtained at flanging outside edge processing

5. Conclusions

Analysis of deformation state at drawing sheet process allowed analytical relationships for calculating the real main strains cylindrical coordinates. The translation relations have been established was determined formulas for the calculation of wall thickness and increasing the height and relative height of the piece due to the radial deformation in the drawing processing.

Thus the coefficient drawing values in the range *0.5-0.8,* the drawing technological calculations will be made with drawing specific relations

For large coefficients drawing , *m> 0.8*, drawing processing can be considered external reflection processing margins because of high growth rates is within the tolerances obtained free dimensions processing on cold plastic deformation.

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