THEORETICAL CONSIDERATION ON FORCE CALCULUS OF THE TOROIDAL AND TOROIDAL WITH CYLINDRICAL COLLAR COLD STRANGLING OF HOLLOW PARTS

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Abstract. *The paper presents the calculation of toroidal and toroidal with cylindrical collar strangling force using energetically method by equalizing the mechanical work of external deformation forces with that of internal strains of the blank deformed zone. Relationships obtained show that the total force of toroidal strangled is influenced by physical and mechanical characteristics of the blank material, size of the toroidal surface, wall thickness of hollow or tubular parts and friction coefficient between the die and the workpiece. Also, to strangle toroidal with collar cylinder influences the connection radius between collar cylindrical and toroidal surface of the mould.*

Keywords: *force necking, toroidal necking, necking coefficient, cylindrical collar*

1. Introduction

Strangling is a cold plastic deformation process category, which consists in decreasing cross-sectional dimension of a hollow, tubular piece or circular bars.

Decreasing cross-sectional dimensions of the material of the blank takes place due by movement in the radial direction from the outside towards the centre of the section.

Hollow tubular blanks or processed by moulding the shape and size changes during processing on the basis of the change wall thickness, although in practical terms it is believed that the wall thickness of the part is the same as the wall thickness of the blank.

Practical application processing is getting various containers, war cartridges tubes, parts installation etc.

Processing is done with moulds which have shape and dimensions of the strangling part.

Shapes that can be obtained through the strangling hollow or tubular parts are conical, conical with collar cylindrical, toroidal and toroidal with cylindrical collar [1].

Assessing the degree of deformation is through the strangling m_g coefficient that should always be higher than the allowable amount for blank m_{ga} used. This coefficient is defined as the ratio between d and D. Its value depends on the characteristics of plasticity of the material, the design of the die, the relative thickness of the walls, etc. [2].

Strangling dies can be designed to realize the necking process free, or necking to support the walls during constriction [2].

Function shape and size part precision and strangling pressing force, strangling constructive mould is choosing.

Free deformation constriction force must be smaller than the force that walls lose their stability.

It is necessary to know the strangling force and for choosing of pressing machine that is processed.

2. Calculation of toroidal strangling force.

A toroidal surface is obtained when strangling is made with a radius $R_m \triangleleft R$, and if $R_m = R$ is spherical necking.

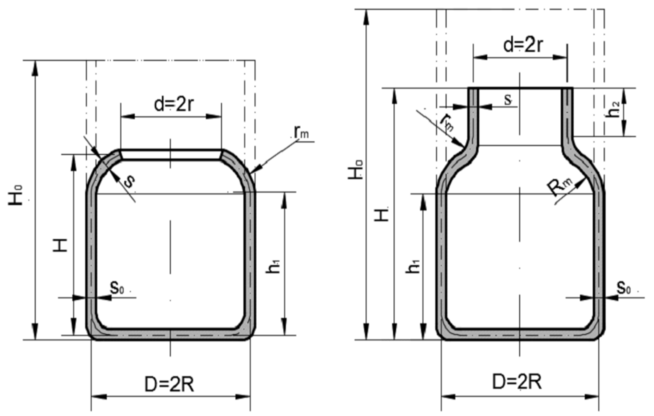

Figure. 1.
Strangling toroidal forms
a- simple toroidal; b-toroidal with cylindrical collar

During toroidal strangling deformation themould acts upon workpiece by force $\overline{N}$ (figure 2). Between toroidal surface of the mould and workpiece occurs during deformation frictional force $\overline{F_{f.}}$.

By composing the force $\overline{N}$ and $\overline{F_{f.}}$ the resultant force $\overline{R}$ is obtained. Vertical projection of force $\overline{R}$ is the force $\overline{F_{tg}}$ required to be applied to achieve constriction toroidal mould.

So it can be written:

$$\overline{F_{tg}} = \overline{F_g} + \overline{F_{fv}} \qquad (1)$$

were $\overline{F_g}$ it is the vertical component deformation force $\overline{N}$ and F_{fv} is the vertical component of friction force $\overline{F_{f.}}$.

Corresponding to figure 2 can be written:

$$F_{fv} = F_f \cos\alpha \qquad (2)$$

$$N = \frac{F_g}{\sin\alpha} \qquad (3)$$

$$F_f = \mu N \qquad (4)$$

By substituting equations (2), (3) and (4) in (5) is obtained:

$$F_{tg} = F_g(1 + \mu\, ctg\alpha) \qquad (5)$$

Amount strangling force value can be calculated using the energy method to equal the external work of stranglig force L_e, with the work of internal tensions L_i, that arise during plastic deformation:

$$L_e = L_i \qquad (6)$$

The elementary work of internal tensions can be determined from the relationship [2]:

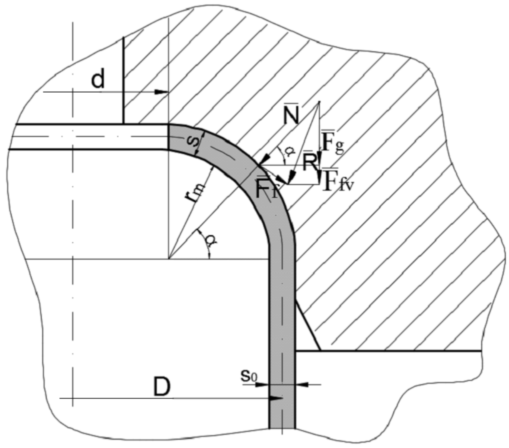

Figure. 2. *Toroidal strangling force system*

$$dL_i = \sigma_c \varepsilon_i \, dV \qquad (7)$$

in witch σ_c is the yield strength of the material blank; ε_i-deformations intensity in point *M* (fig. 3); *dV*- elementary volume that is deformed by consuming dL_i elementary mechanical work.

The intensity of deformations can be determined by the relationship:

$$\varepsilon_i = \sqrt{(\varepsilon_\rho - \varepsilon_\theta)^2 + (\varepsilon_\theta - \varepsilon_z)^2 + (\varepsilon_z) - \varepsilon_\rho)^2} \qquad (8)$$

where ε_ρ, ε_θ and ε_z are the main deformations direction ρ, θ and *z* (fig. 3).

The main deformation ε_θ in the circumferential direction, corresponding to figure 3, is defined by the equation:

$$\varepsilon_\theta = \frac{\rho(\alpha) - R}{R} \qquad (9)$$

in which

$$\rho(\alpha) = R - R_m(1 - \cos\alpha) \qquad (10)$$

If you replace the expression (10) into (9) we obtain:

$$\varepsilon_\theta = -\frac{R_m}{R}(1 - \cos\alpha) \qquad (11)$$

Elementary volume *dV* corresponding figure 3 can be determined by the relationship:

$$dV = dA\, s \qquad (12)$$

in which:

$$dA = \rho(\alpha)\, d\theta\, R_m\, d\alpha \qquad (13)$$

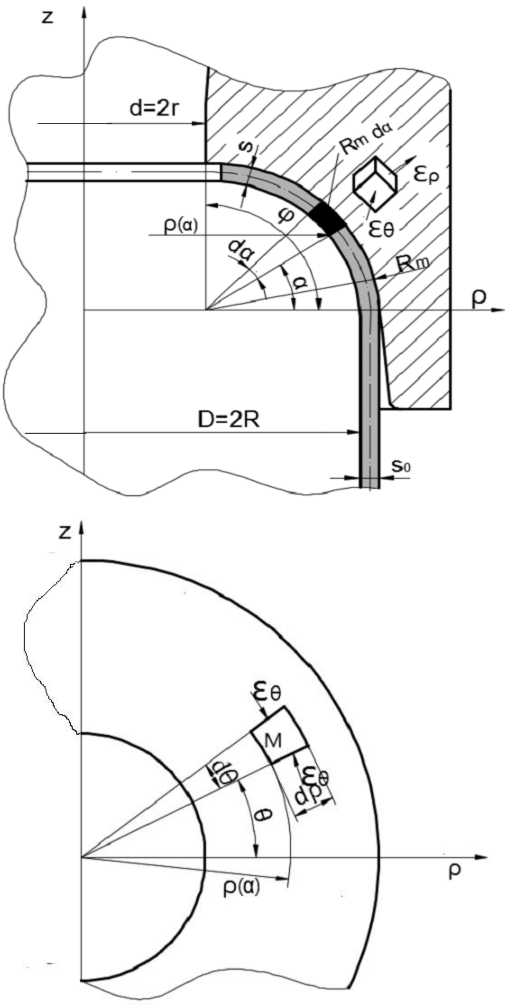

Figure 3 *Blank deformation scheme at toroidal strangling*

By replacing dA in (12) and taking into account the relation (10) follows:

$$dV = \left[R - Rm(1-\cos\alpha)\right] R_m s\, d\theta d\alpha \qquad (14)$$

If apply the law of volume constancy of cold plastic deformation at volume dV, can write:

$$\varepsilon_\rho + \varepsilon_\theta + \varepsilon_z = 0 \qquad (15)$$

With some approximation, because the deformation is small z-axis direction, can be considered $\varepsilon_z \approx 0$, and we can write:

$$\varepsilon_\rho = -\varepsilon_\theta \qquad (16)$$

Size specific deformation of walls in the radial direction ε_ρ may be determined by the equation:

$$\varepsilon_\rho = \frac{s - s_0}{s_0} \qquad (17)$$

where: s_0 it is the initial thickness of the blank walls; s -deformed thickness in point M of blank.

From equation (17), taking into account the relations (11) and (16) gives the thickness s and thus:

$$s = \frac{s_0}{R}\left[R + (1-\cos\alpha)\right] \qquad (18)$$

With the value of s defined by (18) replaced in (14) follows:

$$dV = s_0 \frac{R_m}{R}\left[R^2 - R_m^2(1-\cos\alpha)^2\right] d\theta\, d\alpha \qquad (19)$$

Deformations intensity value may be located by substituting equations (11), (16) and (18) into equation (8) to give:

$$\varepsilon_i = \frac{2}{\sqrt{3}} \frac{R_m}{R}(1-\cos\alpha) \qquad (20)$$

Using relations (7), (19) and (20) gives the formula for calculating the elementary mechanical work of internal tensions, as follows:

$$dL_i = \frac{2}{\sqrt{3}} \sigma_c s_0 \frac{R_m^2}{R^2}(1-\cos\alpha)\left[R^2 - R_m^2(1-\cos\alpha)^2\right] d\theta d\alpha \qquad (21)$$

By integrating the relation (21) for the variable θ from 0 to 2π and the variable α from 0 to φ it obtain L_i with the form:

$$L_i = \frac{4\pi}{\sqrt{3}} \sigma_c s_0 \int_0^{\varphi} \left[R^2(1-\cos\alpha) - R_m^2(1-\cos\alpha)^3\right] \frac{R_m^2}{R^2}\, d\alpha \qquad (22)$$

After the calculation results:

$$L_i = \frac{4\pi}{\sqrt{3}} \sigma_c s_0 R_m^2 \Big\{\varphi - \sin\varphi - \frac{R_m^2}{R^2}\Big[\varphi - 3\sin\varphi + \frac{3}{2}(\varphi + \sin\varphi\cos\varphi) - \frac{1}{3}\sin\varphi(\cos^2\varphi + 2)\Big]\Big\} \qquad (23)$$

The mechanical work of the external strangling force F_g can be determinated by relationship:

$$L_e = \lambda\, F_g h \qquad (24)$$

in which $\lambda \approx 0{,}5$, because the deformation force increases from 0 to the maximum value F_g, and h is the displacement in load.

Corresponding to figure 3, the displacement in load h it can also be determined by the relationship:

$$h = R_m \varphi \qquad (25)$$

Substituting equation (25) to (24) was obtained:

$$L_e = \frac{1}{2} F_g\, R_m\, \varphi \qquad (26)$$

Equalling relation (23) with (26) follows:

$$F_g = \frac{8\pi}{\sqrt{3}}\sigma_c s_0 \frac{R_m}{\varphi}\left\{\varphi - \sin\varphi - \frac{R_m^2}{R^2}\left[\varphi - 3\sin\varphi + \frac{3}{2}\left(\varphi + \sin\varphi\cos\varphi\right) - \frac{1}{3}\sin\varphi(\cos^2\varphi + 2)\right]\right\} \quad (27)$$

For practical cases may neglect some of the terms that are low and safety may be use relation (27) as simple:

$$F_g = \frac{8\pi}{\sqrt{3}}\sigma_c s_0 \frac{R_m}{\varphi}\left(1 - \frac{\sin\varphi}{\varphi}\right) \quad (28)$$

This value of F_g be replaced in relationship (5) to give the total strangling toroidal force F_{tg} shape:

$$F_{tg} = \frac{8\pi}{\sqrt{3}}\sigma_c\, s_0\, R_m\left(1 - \frac{\sin\varphi}{\varphi}\right)\left(1 + \mu\, ctg\varphi\right) \quad (29)$$

3. Calculation of toroidal with cylindrical collar necking force

Machining of strangled part with cylindrical collar is a machining of strangled toroidal part, where the mold deformation continues after the strangled diameter the value $d + 2r_m(1 - \cos\varphi)$.

Continued deformation blank after they reached this value it causes the material to bend and straighten the final on walls mould, forming a cylindrical collar with diameter *d* (figure 4).

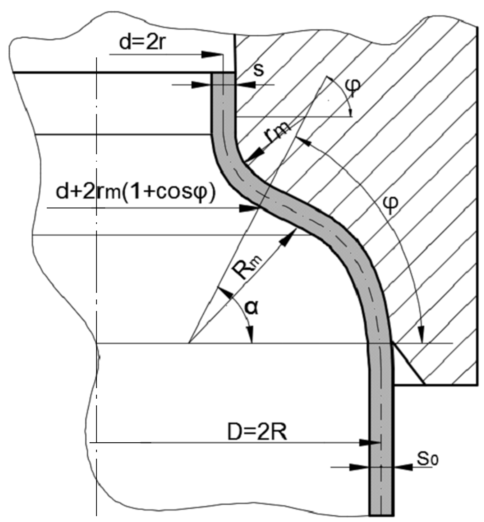

Figure 4. *Toroidal with cylindrical collar strangling*

Thus, the total strangling force F_t in this case would consist of two components: the total strangling force
F_{tg} , and bending and straightening force across r_m mould $F_{\hat{i}}$, as:

$$F_t = F_{tg} + F_{\hat{i}} \quad (30)$$

Bending and straightening force of the blank across r_m is determined from the equalizing of mechanical the work of the inner bending moment on the angle with mechanical the work of force $F_{\hat{i}}$. The phenomenon is similar to the conical and cylindrical collar strangling, and calculation of expression $F_{\hat{i}}$ will be the following form [1]:

$$F_{\hat{i}} = \frac{1{,}82\sigma_r s_0^2\left(1 + \frac{d}{r_m} - \cos\varphi\right)}{m_g} \quad (31)$$

Substituting relations (29) and (31) in (30) gives the formula for calculating the total force of toroidal with cylindrical collar force F_t form:

$$F_{tg} = \frac{8\pi}{\sqrt{3}}\sigma_c\, s_0\, R_m\left(1 - \frac{\sin\varphi}{\varphi}\right)\left(1 + \mu\, ctg\varphi\right) + \frac{1{,}82\sigma_r s_0^2\left(1 + \frac{d}{r_m} - \cos\varphi\right)}{m_g} \quad (32)$$

4. Conclusions

Toroidal strangling process analysis shows that in this case the total force of the strangling is less than if conical strangling at the same degree of deformation. This is explained by the way in which the contact between tool and workpiece and inclusive in which takes place the deformation.

For toroidal with cylindrical collar strangling total deformation force at toroidal strangling force add the necessary training collar force that has the same shape as the conical with cylindrical collar strangling.

Toroidal strangling force is influenced by physical and mechanical characteristics of the material, the thickness of the blank, the radius of the generator tor arc, the angle of the generator arc tor and coefficient of friction.

At toroidal with cylindrical collar strangling, add the total force influencing the radius continues of the mould between the cylindrical surface and tor, and the strangling coefficient.

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