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ANALYSIS OF THE PLASTIC FLOW DURING THE FORWARD-BACKWARD HOT EXTRUSION USING THIN SECTIONS METHOD

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ABSTRACT
This study analyses the possibility of applying the Thin Sections Method for calculation for extrusion pressure for combined forward-backward extrusion. It also deals with the possibility of increasing the accuracy of the method. By using this method it is possible to obtain data concerning the pressure distribution along the punch face. The results have been tested experimentally.
Keywords: theory of plasticity, combine extrusion, thin sections method.

1. INTRODUCTION
The expressions for some important parameters used for extrusion processes, as for example the extrusion pressure can be derived by applying classical methods of the metal forming theory [1], [2]. However, there is also a large number of experimentally obtained formulas [1], [3]. Most of the experimentally obtained expressions have a constrained range of application since they can only be used for the range of parameters which are similar to the conditions of the experiment from which the expressions are derived. Usually, these formulas don't provide information concerning the distribution of pressure along the punch face. The presence of high specific pressures, especially on the punch face can act as a constraint for application of the deformation processes, since this fact brings up the question of tool durability and the quality of lubrication.

2. THE APPROXIMATE EQUILIBRIUM EQUATION
Determining the expressions for pressure in extrusion processes using the Thin Sections Method implies certain assumptions which result in several expressions for calculation of force and the level of complexity of these expressions varies widely. One thin section with acting forces for the combined extrusion case is given in Figure 1.

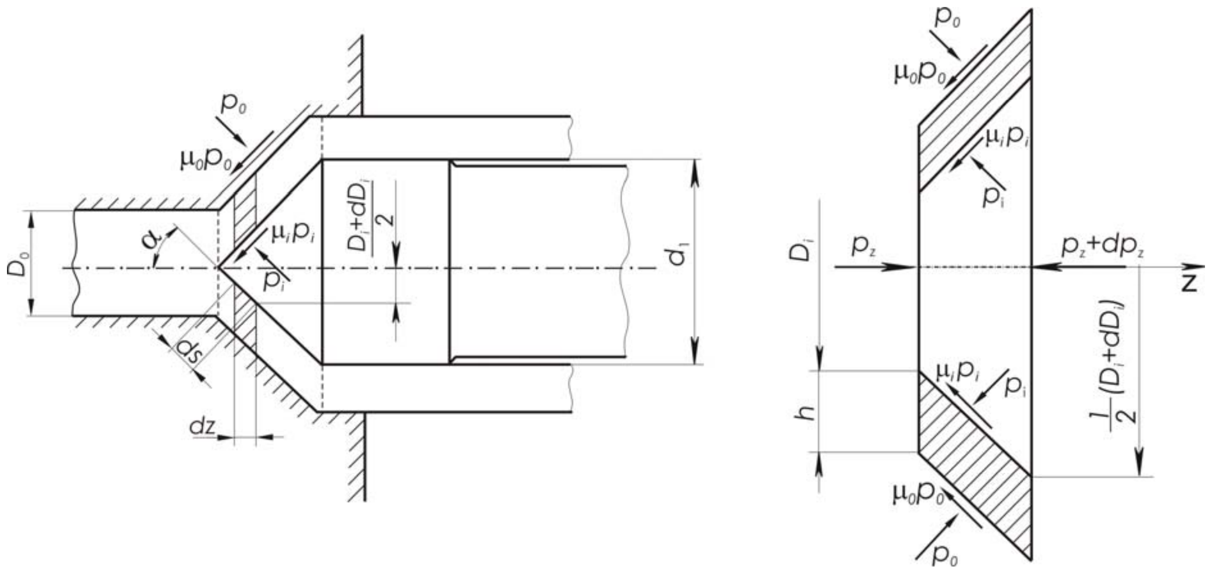

Figure 1. One thin section with acting forces.

The differential equation of equilibrium for one thin section for the general case of combined forward-backward extrusion with a conical punch (Figure 1) is:

$$\begin{aligned}&p_z\left[\left(D_i+2h\right)^2-D_i^2\right]\frac{\pi}{4}-\left(p_z+dp_z\right)\left[\left(D_i+2h+dD_i\right)^2-D_i^2\right]\frac{\pi}{4}-\\&-\mu_0 p_0\left(D_i+2h\right)\pi ds\cos\alpha+p_0\left(D_i+2h\right)\pi ds\sin\alpha-\\&-\mu_i p_i D_i\pi ds\cos\alpha-p_i D_i\pi ds\sin\alpha=0\end{aligned}\qquad\ldots(1)$$

Where p_z, p_i and p_0 are the pressure in extrusion direction, inner and outer pressure respectively, D_i is the inner diameter and μ_i, μ_0 are the friction coefficient between punch-workpiece and die-workpiece respectively. It is reasonably to introduce the assumptions: $p_i = p_0$ and $\mu_i = \mu_0$, and after neglecting the second order of differential quantities, equation (1) become:

$$\frac{dp_z}{-p_i+p_z-\mu p_i ctg\alpha\left(1+\frac{D_i}{h}\right)}=\frac{dD_i}{D_i+h}\qquad\ldots(2)$$

In the deformation zone the yield condition must be satisfied. The Tresca yield criteria for the axi-symmetric case ($\sigma_2 = \sigma_3$) is $\sigma_2 - \sigma_3 = k_f$, so after applying this criteria for considering case, one can obtain the equation:

$$p_i = p_z + k_f,\qquad\ldots(3)$$

and finally, the following differential equation is obtained:

$$\frac{dp_z}{k_f-\mu\cdot\text{ctg}\alpha\left(1+\frac{D_i}{h}\right)\left(k_f+p_z\right)}=\frac{dD_i}{D_i+h}\qquad\ldots(4)$$

If the stresses which a result of friction are neglected, equation (4) can be solved directly, otherwise, it must be solved numerically.

3. THE APPLICATION OF THIN SECTION METHOD

In order to apply the thin sections method, it is necessary to divide the deformation zone, which is surrounded by the dashed line in Figure 1, into m elementary layers of equal width – dz. Observing the equilibrium of each layer, beginning with the first layer of maximum diameter d_1 and ending with the last one with diameter D_m, for each layer, it is possible to formulate the equation (4). By adding up the increments of pressure for each new layer, the average pressure on the punch face is obtained as a final result:

$$p = \frac{d_1}{m} \sum_{n=1}^{m} \left[k_f - \mu \cdot \mathrm{ctg}\alpha \left(1 + \frac{D_n}{h}\right)\left(k_f + p_{z_{n-1}}\right)\right] \frac{D_n}{D_n + h} \qquad \text{...(5)}$$

As one can see, the pressure of each previous n-th layer is transferred to the next n+1th layer which borders the previous layer. The starting value for the first layer (layer with max. diameter) represents the boundary condition where $D_i = d_i$ and therefore the pressure p_z =0, since the material located to the right of the first layer does not flow, but it moves as a rigid body.

The diameters of the first and last thin sections are given by:

$$D_1 = d_1 - \frac{d_1}{2m} \qquad \text{...(6)}$$

and

$$D_m = \frac{d_1}{2m} \qquad \text{...(7)}$$

The accuracy will be greater if the number of layer m is increased. At the same time, it is very hard to perform such calculations without using a computer. Generally, the plastic yield stress k_f must be given as a function of the degree of deformation, i.e. $k_f = k_f(\varepsilon)$ due to the possibility of input into the program, since it has to be calculated for each new thin section, as a function of geometrical rations of the observed section.

4. EXPERIMENTAL TESTING

The experimental verification of the presented method was done by measuring the extrusion pressure for the case of combined forward-backward hot extruded part given on the figure 2. The workpiece dimensions and process parameters are given in Table 1.

Table 1. The workpiece dimensions and process parameters

1.	Workpiece material	Č.4135VP
2.	Temperature of workpiece	1125÷1175 ^{0}C
3.	Temperature of tooling	475÷635 ^{0}C
4.	Yield stress	21 MPa
5.	Friction coefficient (μ)	0,15
6.	Ram velocity	125 mm/s
7.	Outer diameter	127 mm
8.	Inner diameter (d_1)	107 mm
9.	Angle of cone (α)	62^0

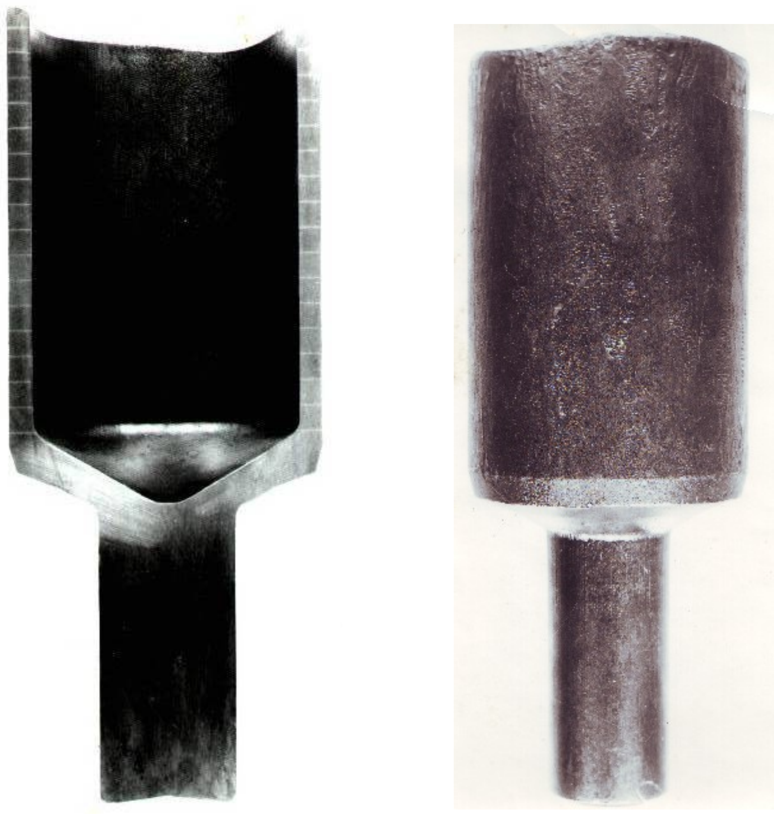

Figure 2. The workpiece.

The calculated and experimentally obtained results for this case are in good correlation. The experimentally obtained value of deformation pressure was is the range p=27,5÷30 MPa, while the thin sections method gives p= 26,5 MPa. The number of thin sections in calculation was 35. The yield stress during calculation is assumed constant (non-strain-hardening) and the friction coefficient also. These assumptions give the basic reasons for the differences between experimentally and calculated obtained results.

5. CONCLUSION

The thin section method applied for calculation of pressure in extrusion process can give quite accurate results if we do not consider the assumptions and approximations made along the way. However, this will result in complex equations which can only be solved numerically. The basic assumptions for achieving good accuracy are: the precise information about material properties given as an analytical expression (yield curve), the boundary conditions (friction coefficient) and dividing the deformation zone into the enough number of thin sections.

6. REFERENCES

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