# On the Demolding Force Calculation in the Case of Plastics Thin-Wall Injected Parts

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*In this paper the calculation methods of the demolding force in case of thin-wall injected plastic parts with linear, curvilinear or combined profile are presented. The magnitude of this force directly influences the constructive solution of the ejector system.*

*Key words: injected part, demolding force, ejector system*

The design of the pneumatic ejector systems should take into account many factors, such as the demolding force (the necessary force for separation the injected part from the mold). The magnitude of this force directly influences the design solution of the pneumatic ejector system of the injection mold.

In figure 1 [1] an example of a pneumatic ejector system for a thin-wall part with combined profile is presented.

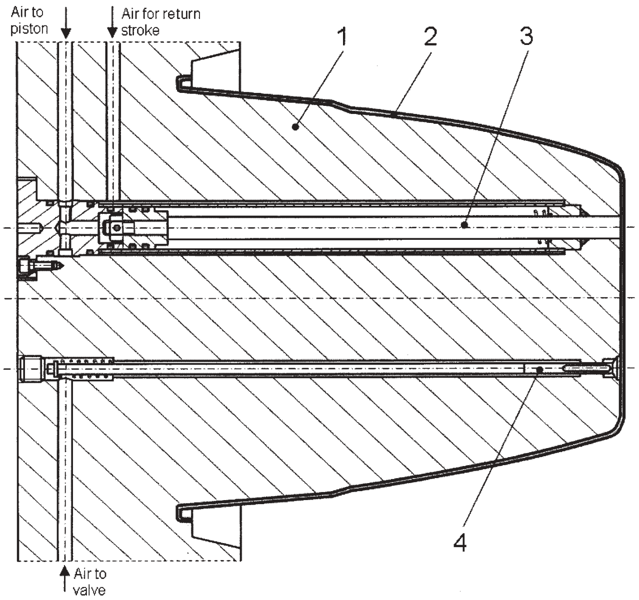


Fig. 1. Pneumatic ejector system. 1-core; 2-part; 3-pneumatic ejector, 4-air valve

At the opening of the mold, the part remains on the core due to the material contraction. At the end of the opening stroke, the air passes through the valve between the core and the bottom of the part wall (the part being elastic) and the part is detached from the core. In fact, the detaching of the part is a two stages process. The bottom of the part wall is detached in the first stage. Therefore, in the demolding force calculation, the contact area between the part and the core is the side area of the part.

The ejection force is:

$$F_A = F_D + \Sigma F_R \qquad (1)$$

where

$F_D$ is the demolding force;

$F_R$ - friction forces in the mold system.

In the case of the pneumatic ejector systems these friction forces are negligible.

$$F_{Ra} = F_d \qquad (2)$$

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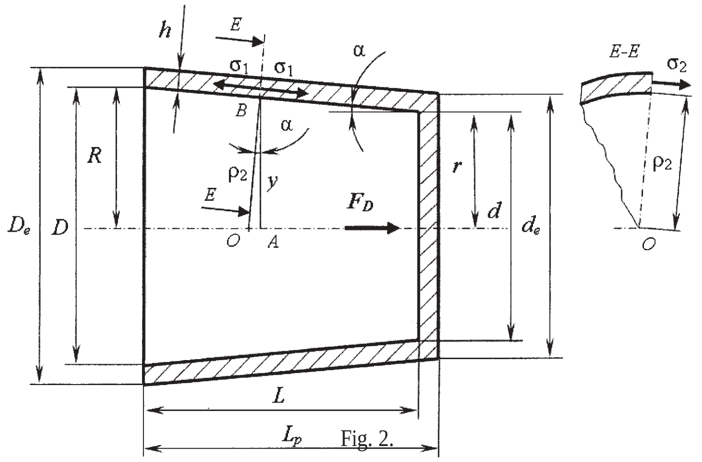


Fig. 2.

*The demolding force calculation for parts with linear profile*

The demolding force calculation is performed taking into account the figure 2 [1].

According to [3]:

$$F_D = \mu \cdot p \cdot \boldsymbol{A} \qquad (3)$$

where $\mu$ is the coefficient of friction between the injected part and the core.

The coefficient of friction is experimentally determined and it depends on the injected plastic material and on the manufacturing quality of the mold active surfaces;

$p$ - contact pressure between the part and the core;

$A$ - contact area between the part and the core.

The International System of Units (SI) is used in the above equation and in those that follows.

The pressure $p$ is calculated considering the analogy with thin-wall taper vessel model charged with internal pressure.

The relationship between pressure, stresses and geometric dimensions of the taper vessel is given by the Laplace equation:

$$\frac{\sigma_1}{\rho_1} + \frac{\sigma_2}{\rho_2} = \frac{p}{h} \qquad (4)$$

where

$\sigma_1$ is the meridian tension;

$\sigma_2$ - circumferential tension;

$\rho_1$ - first main curvature radius;

$\rho_2$ - second principal curvature radius;

$p$ - contact pressure;

$h$ - wall thickness of the injected part.

According to [2]:

$$\sigma_1 = \sigma_2 = E_{(T)} \cdot \varepsilon_{(T)} \qquad (5)$$

where

$E_{(T)}$ is the modulus of elasticity of the injected part (at the demolding temperature);

$\varepsilon_{(T)}$ - specific contraction of the material (at the demolding temperature).

In the thin-wall taper vessel case $\rho_1 = \infty$ and from the equation (4) yields:

$$\frac{\sigma_2}{\rho_2} = \frac{p}{h} \quad \Rightarrow \quad p = \sigma_2 \cdot \frac{h}{\rho_2} \tag{6}$$

From figure 2 results: $\rho_2 = \dfrac{y}{\cos\alpha}$ (7)

From the equations (5, 6 and 7) results:

$$p = E_{(T)} \cdot \varepsilon_{(T)} \cdot \frac{h \cdot \cos\alpha}{y} \tag{8}$$

It can noted be that the contact pressure is variable, and reaches its maximum value for $y = r$. This maximum value can be used at the demolding force calculation:

$$p = E_{(T)} \cdot \varepsilon_{(T)} \cdot \frac{h \cdot \cos\alpha}{r} \tag{9}$$

In this case, as we already mentioned above, the contact area $A$ between the part and the core is the side area of the part:

$$A = \pi \cdot \frac{L}{\cos\alpha} \cdot (R + r) \tag{10}$$

From the equations (3, 9 and 10) it can be obtained:

$$F_D = \mu \cdot E_{(T)} \cdot \varepsilon_{(T)} \cdot \frac{h}{r} \cdot \pi \cdot L \cdot (R + r) \tag{11}$$

The demolding force for a taper part can be calculated with the equation (11), knowing the material and the geometric dimensions of the part.

*The demolding force calculation for parts with curvilinear profile*

The demolding force calculation is carried out taking into account the figure 3 [1].

The pressure $p$ is calculated considering the analogy with the model of solid of revolution charged with internal pressure.

From the Laplace equation:

$$\frac{\sigma_1}{\rho_1} + \frac{\sigma_2}{\rho_2} = \frac{p}{h} \quad \Rightarrow \quad p = h \cdot \left( \frac{\sigma_1}{\rho_1} + \frac{\sigma_2}{\rho_2} \right) \tag{12}$$

From the equations (5) and (12) yields:

$$p = E_{(T)} \cdot \varepsilon_{(T)} \cdot h \cdot \left( \frac{1}{\rho_1} + \frac{1}{\rho_2} \right) \tag{13}$$

In this case: $\rho_1 = R = ct.$ (14)

where

$R$ is the curvature radius of the part profile.

$\rho_2$ is calculated from figure 3:

$$\Delta ABC \sim \Delta EDC \quad \Rightarrow \quad \frac{AB}{ED} = \frac{AC}{EC} \quad \Rightarrow \quad \frac{a}{R - \rho_2} = \frac{r_y}{\rho_2} \tag{15}$$

$$\rho_2 = \frac{R}{1 + \dfrac{a}{r_y}} \tag{16}$$

From the equations 13, 14 and 16 results:

$$p = E_{(T)} \cdot \varepsilon_{(T)} \cdot \frac{h}{R} \cdot \left( 2 + \frac{a}{r_y} \right) \tag{17}$$

One can note that the contact pressure is variable, and reaches its maximum value for $r_y = r_1$. This maximum value can be used at the demolding force calculation:

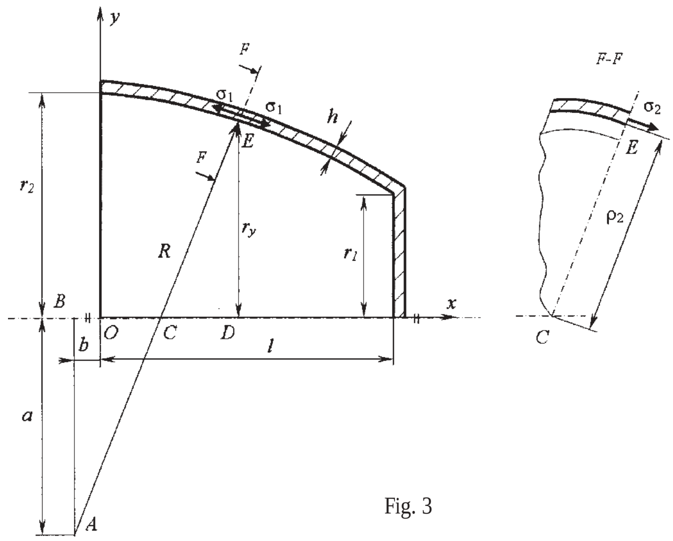


Fig. 3

$$p = E_{(T)} \cdot \varepsilon_{(T)} \cdot \frac{h}{R} \cdot \left( 2 + \frac{a}{r_1} \right) \tag{18}$$

In figure 3 the coordinate system Oxy is considered. The part profile is an arc of a circle, the equation of this circle is:

$$(x + b)^2 + (y + a)^2 = R^2 \tag{19}$$

$$y = \sqrt{R^2 - (x + b)^2} - a \tag{20}$$

consequently $f(x) = \sqrt{R^2 - (x + b)^2} - a$ (21)

$$A = 2 \cdot \pi \cdot \int_0^l f(x) \cdot \sqrt{1 + (f'(x))^2}\, dx \tag{22}$$

From the equations (21) and (22) results:

$$A = 2 \cdot \pi \cdot R \cdot \left( x - a \cdot \arcsin \frac{x + b}{R} \right) \Bigg|_0^l =$$

$$= 2 \cdot \pi \cdot R \cdot \left[ l - a \cdot \left( \arcsin \frac{l + b}{R} - \arcsin \frac{b}{R} \right) \right] \tag{23}$$

From the equations (3), (18) and (25) results:

$$F_D = 2 \cdot \pi \cdot \mu \cdot E_{(T)} \cdot \varepsilon_{(T)} \cdot h \cdot \left( 2 + \frac{a}{r_1} \right) \cdot$$

$$\cdot \left[ l - a \cdot \left( \arcsin \frac{l + b}{R} - \arcsin \frac{b}{R} \right) \right] \tag{24}$$

The demolding force for thin-wall parts with curvilinear profile can be calculated with equation (24), knowing the material and the geometric dimensions of the part.

*The demolding force calculation for parts with combined profile*

A thin-wall part with combined profile is shown in figure 1. One portion of the profile part is curvilinear (arc of a circle) and the other one is linear.

The demolding force calculation is performed taking into account the figure 4 [1].

In this case:

$$F_D = F_{D1} + F_{D2} \tag{25}$$

where

$F_{D1}$ is the demolding force corresponding to the curvilinear profile portion of the part;

$F_{D2}$ - demolding force corresponding to the linear profile portion of the part.

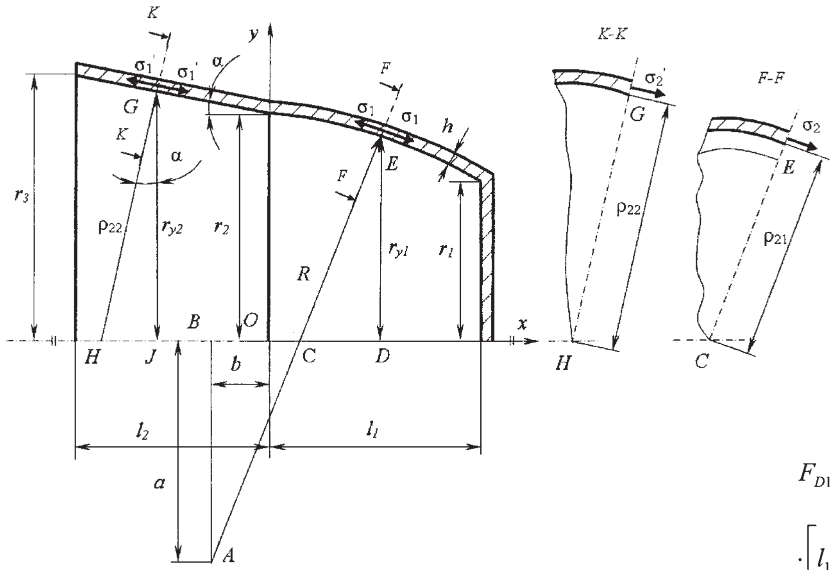


Fig. 4. The demolding force calculation corresponding to the curvilinear profile portion of the part

$$F_{D1} = \mu \cdot p_1 \cdot A_1 \tag{26}$$

From the Laplace equation:

$$\frac{\sigma_1}{\rho_{11}} + \frac{\sigma_2}{\rho_{21}} = \frac{p_1}{h} \quad \Rightarrow \quad p_1 = h \cdot \left( \frac{\sigma_1}{\rho_{11}} + \frac{\sigma_2}{\rho_{21}} \right) \tag{27}$$

where $\rho_{11}$ is the first main curvature;
$\rho_{21}$ - second main curvature radius;
$p_1$ - contact pressure;

From the equations (5) and (27) results:

$$p_1 = \mathrm{E}_{(\mathrm{T})} \cdot \varepsilon_{(\mathrm{T})} \cdot h \cdot \left( \frac{1}{\rho_{11}} + \frac{1}{\rho_{21}} \right) \tag{28}$$

In this case: $\rho_{11} = R = ct.$ (29)
where $R$ is the curvature radius of the part.
$\rho_{21}$ is calculated from figure 4:

$$\Delta ABC \sim \Delta EDC \quad \Rightarrow \quad \frac{AB}{ED} = \frac{AC}{EC} \quad \Rightarrow \quad \frac{a}{R - \rho_{21}} = \frac{r_y}{\rho_{21}} \tag{30}$$

$$\rho_{21} = \frac{R}{1 + \frac{a}{r_y}} \tag{31}$$

From the equations (28), (29) and (31) yields:

$$p_1 = \mathrm{E}_{(\mathrm{T})} \cdot \varepsilon_{(\mathrm{T})} \cdot \frac{h}{R} \cdot \left( 2 + \frac{a}{r_y} \right) \tag{32}$$

It ca be noted that the contact pressure is variable and reaches its maximum value for $r_y = r_1$. This maximum value is used for the demolding force calculation:

$$p_1 = \mathrm{E}_{(\mathrm{T})} \cdot \varepsilon_{(\mathrm{T})} \cdot \frac{h}{R} \cdot \left( 2 + \frac{a}{r_1} \right) \tag{33}$$

In figure 4 the coordinate system Oxy is considered. The part profile is a circular arc.

From the equations (21) and (22) (adjusted for this case, with $A_1$ and $l_1$) results:

$$A_1 = 2 \cdot \pi \cdot R \cdot \left( x - a \cdot \arcsin \frac{x+b}{R} \right) \Bigg|_0^{l_1} =$$

$$= 2 \cdot \pi \cdot R \cdot \left[ l_1 - a \cdot \left( \arcsin \frac{l_1 + b}{R} - \arcsin \frac{b}{R} \right) \right] \tag{34}$$

From the equations (26), (33) and (34) results:

$$F_{D1} = 2 \cdot \pi \cdot \mu \cdot \mathrm{E}_{(\mathrm{T})} \cdot \varepsilon_{(\mathrm{T})} \cdot h \cdot \left( 2 + \frac{a}{r_1} \right) \cdot$$

$$\cdot \left[ l_1 - a \cdot \left( \arcsin \frac{l_1 + b}{R} - \arcsin \frac{b}{R} \right) \right] \tag{35}$$

*The demolding force calculation for the linear profile portion of the part*

$$F_{D2} = \mu \cdot p_2 \cdot A_2 \tag{36}$$

From the Laplace equation:

$$\frac{\sigma'_1}{\rho_{12}} + \frac{\sigma'_2}{\rho_{22}} = \frac{p_2}{h} \quad \Rightarrow \quad p_2 = h \cdot \left( \frac{\sigma'_1}{\rho_{12}} + \frac{\sigma'_2}{\rho_{22}} \right) \tag{37}$$

In this case: $\rho_{12} = \infty$ and $\rho_{22} = \frac{y}{\cos \alpha}$. (38)

From the equations (5) (adjusted for this case, with $\sigma'_1$ and $\sigma'_2$), (37) and (38) results:

$$p_2 = \mathrm{E}_{(\mathrm{T})} \cdot \varepsilon_{(\mathrm{T})} \cdot \frac{h \cdot \cos \alpha}{y} \tag{39}$$

It can be noted that the contact pressure is variable, it reaches the maximum value for $y = r_2$. This maximum value is used for the demolding force calculation:

$$p_2 = \mathrm{E}_{(\mathrm{T})} \cdot \varepsilon_{(\mathrm{T})} \cdot \frac{h \cdot \cos \alpha}{r_2} \tag{40}$$

The contact area $A_2$ between the part and the core is:

$$A_2 = \pi \cdot \frac{l_2}{\cos \alpha} \cdot (r_3 + r_2) \tag{41}$$

From the equations (36), (40) and (41) results:

$$F_{D2} = \pi \cdot \mu \cdot \mathrm{E}_{(\mathrm{T})} \cdot \varepsilon_{(\mathrm{T})} \cdot h \cdot l_2 \cdot \left( 1 + \frac{r_3}{r_2} \right) \tag{42}$$

*The demolding force calculation*

From the equations (25), (35) and (42) yields:

$$F_D = \pi \cdot \mu \cdot \mathrm{E}_{(\mathrm{T})} \cdot \varepsilon_{(\mathrm{T})} \cdot h \cdot \left[ 2 \cdot \left( 2 + \frac{a}{r_1} \right) \cdot \right.$$

$$\left. \cdot \left[ l_1 - a \cdot \left( \arcsin \frac{l_1 + b}{R} - \arcsin \frac{b}{R} \right) \right] + l_2 \cdot \left( 1 + \frac{r_3}{r_2} \right) \right] \tag{43}$$

The demolding force can be calculated with the equation (43), knowing the material and the geometric dimensions of the part.

In order to obtain the detachment of the part from the core under the combined action of the passing through valve air and of the ejector system the following inequation should be satisfied:

$$F_S + n \cdot F_a > F_D \tag{44}$$

where

$F_s$ is the extraction force (this extraction force is obtained due to the compressed air that passes through the valve);

$F_a$ - acting force of the pneumatic ejector;

$n$ - number of pneumatic ejectors;

$F_D$ - demolding force.

$$F_S = \frac{1}{4} \cdot \pi \cdot d_p^2 \cdot p_{air} \tag{45}$$

where

$d_p$ is the bottom diameter of part;

$p_{air}$ - compressed air pressure ( 0,5...0,8 MPa).

If the demolding force $F_S$ is larger than the sum between the extraction force $F_S$ and action force of the pneumatic ejector(s), the ejection system should be modified by adding a certain number of supplementary channels in the core of the injection mold (fig. 5, [1]). While the air valve is acted, compressed air is introduced through these channels carrying out in this way the expanding of the part and, eventually, its detachment. Obviously, in this case the mold becomes more complex.

## Conclusions

The design of the pneumatic ejector systems should take into account many factors, such as the demolding force. The magnitude of this force directly influences the design solution of the ejector system.

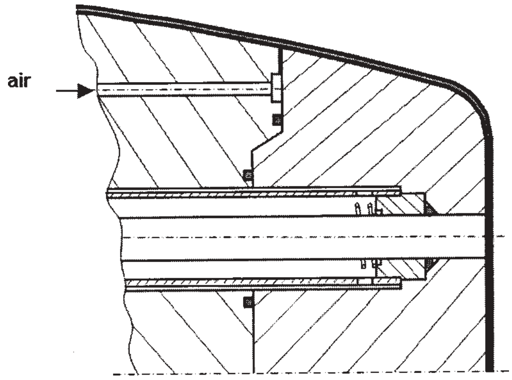


Fig. 5. Supplementary deflation system

The demolding force can be calculated according to the above proposed methods if the material and the geometric dimensions of the injected part are known.

The demolding force $F_D$ is compared with the extraction force $F_s$ and according to their ratio a decision regarding the pneumatic ejector system is made.

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