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PRACTICAL ASPECTS CONCERNING THE DEMOLDING MOMENT CALCULATION FOR INJECTED PARTS WITH EXTERNAL THREAD

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Abstract: *The phenomenon of adhesion represents an essential problem regarding the process of plastic injection process. Furthermore, when the plastic parts have various areas with thread (internal or external with various form i.e. trapezoidal or saw – take for example the classical case of a container's neck finish and the corresponding cap) a demolding moment occurs when the part is detached from the mold. In here, a theoretical step-by-step approach is proposed in order to determine this demolding moment. The approach is applied for different sizes of saw thread profiles. This key parameter of the injection process directly influences the design solution of the ejector system.*
Key words: *injected plastic part, demolding moment, saw thread form.*

1. INTRODUCTION

Plastic injection molding process represents the ideal technology for high volume production of everyday plastic objects such as disposal and reusable parts from medical industry; various types of water bottles and packaging boxes from food and beverage business; the multiple and complex plastic products from automotive industry or from other industries.

Although this process is widespread, there are a few factors that could lead to unappropriated quality of the final parts or even to deformation or cracking [1] of the newly ejected part. One of these factors is the adhesion force. It appears between the mold cavity and molded part. Also, the magnitude of this force directly influences the design solution of the ejector system [2].

In the last few decades there are a few researches that dealt with this problem of adhesion phenomena. Chang and Hwang in [1], described a force tester for measuring the adhesion force during the injection process. Pouzada et al. in [3] developed a new procedure for optimum determination of the plastic injected part surface roughness which conduct to a minimum coefficient of static friction. Pontes et al. in [4] developed a monitoring system in order achieve relevant information about the injection process. The practical mechanical device built up by the authors is used for ejection force determination. Chen and Hwang in [5] investigated the adhesion phenomena which occurs during the injection process. They use an apparatus for measure the adhesion force in the case of three surface roughness conditions. The lower adhesion force was obtained when R_a = 0.08 μm. Wang et al. in [6] present a numerical approach for prediction of the ejection force in the case of injected parts.

In here, the authors consider the complex adhesion phenomena which appears in the case of plastic injected parts with saw thread form. It is known that after the molten material is poured into the mold cavity the newly created part should be ejected as soon as the mold opens. In this particular case, (screw cap or closure screwed onto the corresponding plastic bottle neck) the part will be unscrewed from the mold. At this point a demolding moment occurs [7].

This research represents the final part from a broader study (which include another 3 papers) in which the authors developed several theoretical models for determining the demolding moments for the cases of plastic parts with tread. They are structured as follows: a) injected parts having internal thread with saw [7] or trapezoidal profile [8]; b) injected plastic parts having external thread with trapezoidal profile [9].

In the next section we describe the detailed step by step procedure for calculation of the demolding moment for the injected parts with external saw thread form. Finally, we conclude the discussion with reflections on possible extensions of the study, as well as possible implications in other areas of engineering design.

2. THEORETICAL MODEL FOR THE DEMOLDING MOMENT

During the complex injection molding process of different plastic containers and theirs corresponding caps (which obviously must have matching finishes) molds with mechanical unscrewing of the threaded core (for parts with internal thread i.e. the bottle cap) or cavity (for parts with external thread) are used. In Figure 1 is presented a detailed sketch for the construction of an injection mold used for injection of plastic part whit thread.

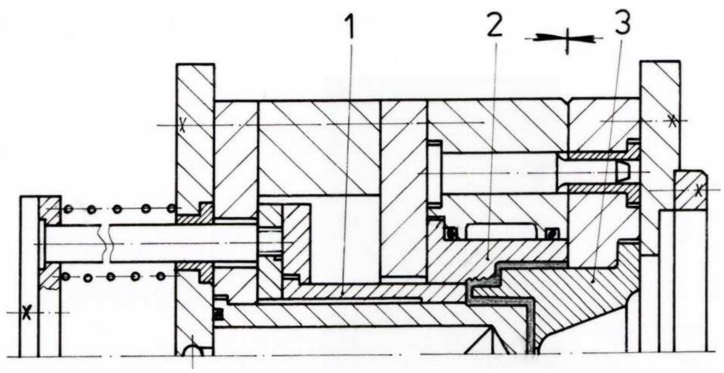

Fig.1 Mold for external thread
1 - ejector; 2 - cavity; 3 - core.

As we already pointed out in the above rows, when the newly created part is unscrewed from the mold cavity a demolding moment appears. This moment, necessary to detach the injected part from the mold core depends of the demolding force and of the dimensions of the injected part.

The demolding force according to [10] is:

$$F_D = \mu \cdot p \cdot A \qquad (1)$$

where: μ represent the coefficient of friction between the injected part and the mold cavity. It depends on the plastic injected material and on the processing quality of the active surfaces of the mold; A is the contact area between the plastic part and the cavity; p represents the contact pressure between the injected part and the mold cavity. Is computed with the following relation [10]:

$$p = \mathrm{E}_{(\mathrm{T})} \cdot \varepsilon_{(\mathrm{T})} \cdot \frac{h}{\rho} \qquad (2)$$

in which: $E_{(T)}$ represents the modulus of elasticity of the injected part (at the demolding temperature); $\varepsilon_{(T)}$ is the specific contraction of the material (at the demolding temperature); h is the wall thickness of the injected part; ρ is the curvature radius of the profile.

3. DEMOLDING MOMENT CALCULATION

In order to determine the mathematical model for the demolding moment which occurs in the case of plastic injected parts with external saw thread is considered the case of a bottle neck finish. A detailed scheme of the thread is presented in Fig. 2. From here it can be seen that the pitch of the thread – ***P*** is composed from two sets of dimensions. Each set has is composed from four linear dimensions, as following: $\boldsymbol{b_1}$, $\boldsymbol{b_2}$, $\boldsymbol{b_3}$, $\boldsymbol{b_4}$ **and** $\boldsymbol{l_1}$, $\boldsymbol{l_2}$, $\boldsymbol{l_3}$, $\boldsymbol{l_4}$. They depend on the main parameters of the thread i.e. external pitch diameter - $\boldsymbol{d_2}$, the length of the neck finish – $\boldsymbol{L}$ and the thickness $\boldsymbol{h}$ of the part wall.

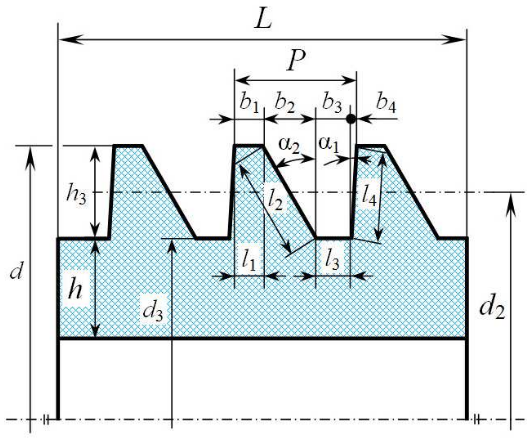

Fig.2 Injected part with external saw thread

The dimensions b_1, b_2, b_3, b_4, respectively l_1, l_2, l_3, l_4 (fig.2) are determined using the following equations:

$$b_1 = 0.26384 \cdot P \quad (3)$$

$$b_2 = \frac{3}{4} \cdot P \cdot \tan \alpha_2 = 0.43301 \cdot P \quad (4)$$

$$b_3 = 0.26384 \cdot P \quad (5)$$

$$b_4 = \frac{3}{4} \cdot P \cdot \tan \alpha_1 = 0.03931 \cdot P \quad (6)$$

$$l_1 = b_1 = 0.26384 \cdot P \quad (7)$$

$$l_2 = \frac{h_3}{\cos \alpha_2} = 1.002 \cdot P \cong P \quad (8)$$

$$l_3 = b_3 = 0.26384 \cdot P \quad (9)$$

$$l_4 = \frac{h_3}{\cos \alpha_1} = 0.89896 \cdot P \quad (10)$$

Also, it is known that, the height of the thread is:

$$h_3 = H_1 + a_c = 0.86777 \cdot P \cong 0.87 \cdot P \quad (11)$$

and the major / minor external diameters are:

$$d_3 = d_2 - 0.75 \cdot P - 2 \cdot a_c = d_2 - 0.98 \cdot P \quad (12)$$

$$d = d_2 + 0.75 \cdot P \quad (13)$$

The clearance at the bottom a_c:

$$a_c = 0.11777 \cdot P \quad (14)$$

For the saw thread the following values are known: α_1=3°, α_2=30°.

The thicknesses of the walls of the injected parts are presented in Figure 3:

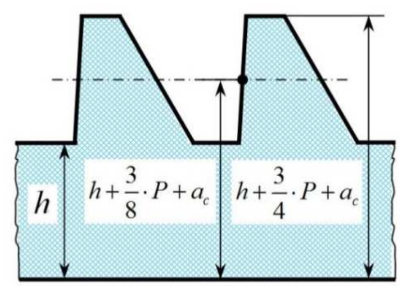

Fig.3 The thicknesses of the part walls

The total lengths of the thread helixes considering the z spires in contact:

$$y_1 = z \cdot \sqrt{(\pi \cdot d)^2 + P^2} = \frac{L}{P} \cdot \sqrt{\pi^2 \cdot (d_2 + 0.75 \cdot P)^2 + P^2} \quad (15)$$

$$y_2 = y_4 = z \cdot \sqrt{(\pi \cdot d_2)^2 + P^2} = \frac{L}{P} \cdot \sqrt{(\pi \cdot d_2)^2 + P^2} \quad (16)$$

$$y_3 = z \cdot \sqrt{(\pi \cdot d_3)^2 + P^2} = \frac{L}{P} \cdot \sqrt{\pi^2 \cdot (d_2 - 0.98 \cdot P)^2 + P^2} \quad (17)$$

The areas of the helix unfolding corresponding to the four sections are:

$$A_1 = l_1 \cdot y_1 = 0.26384 \cdot L \cdot \sqrt{\pi^2 \cdot \left(d_2 + 0.75 \cdot P\right)^2 + P^2} \tag{18}$$

$$A_2 = l_2 \cdot y_2 = L \cdot \sqrt{\left(\pi \cdot d_2\right)^2 + P^2} \tag{19}$$

$$A_3 = l_3 \cdot y_3 = 0.26384 \cdot L \cdot \sqrt{\pi^2 \cdot \left(d_2 - 0.98 \cdot P\right)^2 + P^2} \tag{20}$$

$$A_4 = l_4 \cdot y_4 = 0.86896 \cdot L \cdot \sqrt{\left(\pi \cdot d_2\right)^2 + P^2} \tag{21}$$

The pressures:

$$p_1 = \mathrm{E}_{(\mathrm{T})} \cdot \varepsilon_{(\mathrm{T})} \cdot \frac{h + 0.87 \cdot P}{\frac{d}{2}} = \mathrm{E}_{(\mathrm{T})} \cdot \varepsilon_{(\mathrm{T})} \cdot \frac{2 \cdot \left(h + 0.87 \cdot P\right)}{d_2 + 0.75 \cdot P} \tag{22}$$

$$p_2 = p_4 = \mathrm{E}_{(\mathrm{T})} \cdot \varepsilon_{(\mathrm{T})} \cdot \frac{h + \frac{0.87 \cdot P}{2}}{\frac{d_2}{2 \cdot \sin \alpha_2}} = 0.5 \cdot \mathrm{E}_{(\mathrm{T})} \cdot \varepsilon_{(\mathrm{T})} \cdot \frac{2 \cdot \left(h + 0.44 \cdot P\right)}{d_2} \tag{23}$$

$$p_3 = \mathrm{E}_{(\mathrm{T})} \cdot \varepsilon_{(\mathrm{T})} \cdot \frac{h}{\frac{d_3}{2}} = \mathrm{E}_{(\mathrm{T})} \cdot \varepsilon_{(\mathrm{T})} \cdot \frac{2 \cdot h}{d_2 - 0.98 \cdot P} \tag{24}$$

$$p_4 = \mathrm{E}_{(\mathrm{T})} \cdot \varepsilon_{(\mathrm{T})} \cdot \frac{h + \frac{0.87 \cdot P}{2}}{\frac{d_2}{2 \cdot \sin \alpha_1}} = 0.05234 \cdot \mathrm{E}_{(\mathrm{T})} \cdot \varepsilon_{(\mathrm{T})} \cdot \frac{2 \cdot \left(h + 0.44 \cdot P\right)}{d_2} \tag{25}$$

From (1), (18), (19), (20), (21), (22), (23), (24), and (25) the equations for the demolding forces result:

$$F_{D1} = \mu \cdot p_1 \cdot A_1 = \mu \cdot \mathrm{E}_{(\mathrm{T})} \cdot \varepsilon_{(\mathrm{T})} \cdot 0.26384 \cdot L \cdot \frac{2 \cdot \left(h + 0.87 \cdot P\right)}{d_2 + 0.75 \cdot P} \cdot \sqrt{\pi^2 \cdot \left(d_2 + 0.75 \cdot P\right)^2 + P^2} \tag{26}$$

$$F_{D2} = \mu \cdot p_2 \cdot A_2 = \mu \cdot \mathrm{E}_{(\mathrm{T})} \cdot \varepsilon_{(\mathrm{T})} \cdot 0.5 \cdot L \cdot \frac{2 \cdot \left(h + 0.44 \cdot P\right)}{d_2} \cdot \sqrt{\left(\pi \cdot d_2\right)^2 + P^2} \tag{27}$$

$$F_{D3} = \mu \cdot p_3 \cdot A_3 = \mu \cdot \mathrm{E}_{(\mathrm{T})} \cdot \varepsilon_{(\mathrm{T})} \cdot 0.26384 \cdot L \cdot \frac{2 \cdot h}{d_2 - 0.98 \cdot P} \cdot \sqrt{\pi^2 \cdot \left(d_2 - 0.98 \cdot P\right)^2 + P^2} \tag{28}$$

$$F_{D4} = \mu \cdot p_4 \cdot A_4 = \mu \cdot \mathrm{E}_{(\mathrm{T})} \cdot \varepsilon_{(\mathrm{T})} \cdot 0.04584 \cdot L \cdot \frac{2 \cdot \left(h + 0.44 \cdot P\right)}{d_2} \cdot \sqrt{\left(\pi \cdot d_2\right)^2 + P^2} \tag{29}$$

The demolding moment is:

$$M_D = M_{D1} + M_{D2} + M_{D3} + M_{D4} \tag{30}$$

$$M_{D1} = F_{D1} \cdot \frac{d}{2} = 0.26384 \cdot \mu \cdot E_{(T)} \cdot \varepsilon_{(T)} \cdot L \cdot (h + 0.87 \cdot P) \cdot \sqrt{\pi^2 \cdot (d_2 + 0.75 \cdot P)^2 + P^2} \quad (31)$$

$$M_{D2} = F_{D2} \cdot \frac{d_2}{2} = 0.5 \cdot \mu \cdot E_{(T)} \cdot \varepsilon_{(T)} \cdot L \cdot (h + 0.44 \cdot P) \cdot \sqrt{(\pi \cdot d_2)^2 + P^2} \quad (32)$$

$$M_{D3} = F_{D3} \cdot \frac{d_3}{2} = 0.26384 \cdot \mu \cdot E_{(T)} \cdot \varepsilon_{(T)} \cdot L \cdot h \cdot \sqrt{\pi^2 \cdot (d_2 - 0.98 \cdot P)^2 + P^2} \quad (33)$$

$$M_{D4} = F_{D4} \cdot \frac{d_2}{2} = 0.04584 \cdot \mu \cdot E_{(T)} \cdot \varepsilon_{(T)} \cdot L \cdot (h + 0.44 \cdot P) \cdot \sqrt{(\pi \cdot d_2)^2 + P^2} \quad (34)$$

From the equations (30), (31), (32), (33), and (34) it results:

$$\begin{aligned} M_D = \mu \cdot E_{(T)} \cdot \varepsilon_{(T)} \cdot L \cdot \{ & 0.26384 \cdot [(h + 0.87 \cdot P) \cdot \sqrt{\pi^2 \cdot (d_2 + 0.75 \cdot P)^2 + P^2} + \\ & + h \cdot \sqrt{\pi^2 \cdot (d_2 - 0.98 \cdot P)^2 + P^2}\,] + \\ & + 0.54584 \cdot (h + 0.44 \cdot P) \cdot \sqrt{(\pi \cdot d_2)^2 + P^2}\,\} \end{aligned} \quad (35)$$

$$\begin{aligned} M_D \cong 0.27 \cdot \mu \cdot E_{(T)} \cdot \varepsilon_{(T)} \cdot \pi \cdot L \cdot [& (h + 0.87 \cdot P) \cdot \sqrt{(d_2 + 0.75 \cdot P)^2 + (P/\pi)^2} + \\ & + h \cdot \sqrt{(d_2 - 0.98 \cdot P)^2 + (P/\pi)^2} + (2 \cdot h + 0.87 \cdot P) \cdot \sqrt{d_2^2 + (P/\pi)^2}\,] \end{aligned} \quad (36)$$

With the relation (36) the demolding moment for a plastic injected part with external saw thread can be calculated in the design phase of the mold.

4. NUMERICAL RESULTS

In this section is computed the demolding moment for 12 sizes of saw threads. The plastic part is made up from polyethylene, for which the following properties are known: modulus of elasticity of the injected plastic part at the demolding temperature (60°C), $E_{(T)}$=1150 MPa [10], the coefficient of friction μ=0.31 [10], the specific contraction of the material at the demolding temperature $\varepsilon_{(T)}$=0.01. The results are presented in Table 1.

Table 1

Demolding moments

Thread	Mean diameter d_2 [mm]	Thread pitch P [mm]	Part thickness h [mm]	Part length L [mm]	Demolding moment M_D [N·m]
S 10×2	8.5	2	3	20	8.05
S 12×3	9.75	3	3	20	10.43
S 16×4	13	4	4	25	23.19
S 20×4	17	4	4	25	30.1
S 24×5	20.25	5	5	30	53.84
S 28×5	24.25	5	5	30	64.23
S 32×6	27.25	6	6	35	101.2
S 36×6	31.5	6	6	35	116.6
S 40×7	34.75	7	7	40	171.7
S 44×7	38.75	7	7	40	191.1
S 48×8	42	8	8	45	226.6
S 52×8	46	8	8	45	291.6

5. CONCLUSIONS

The injection process of various plastic part is highly influenced about the adhesion phenomena which occurs between the mold components i.e. the core and the newly injected part. Furthermore, when the part has a complex shape such as certain areas with different thread form i.e. saw or trapezoidal (external or internal) the complex of this phenomenon increases. Moreover, in this case a demolding moment appears. This moment M_D can be calculated according to the above proposed methodology if the material, technological parameters, and the geometric dimensions of the injected part are known. Also, this moment directly influences the design solution of the ejector system.

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Aspecte practice privind calculul momentului de demulare la piese injectate cu filet exterior

Rezumat: Fenomenul de adeziune reprezintă o problemă importantă în cadrul procesul de injectare a pieselor din materiale plastice. Mai mult, atunci când piesele au diverse zone cu filet (interioare sau exterioare cu diferite profile, adică trapezoidale sau ferăstrău - luăm, de exemplu, cazul clasic al unui recipient și a capacului acestuia), un moment de demulare apare atunci când o astfel de piesă este aruncată din matriță. Aici, se propune o abordare teoretică pas cu pas pentru a determina acest moment de demulare. Modelul de calcul este aplicat pentru diferite dimensiuni ale filetului ferăstrău. Valoarea acestui moment influențează în mod direct soluția constructivă a sistemului de aruncare.

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