Demolding Moment Calculation for Injected Parts with Internal Saw Thread

SIMION HARAGAS, OVIDIU BUIGA*, CLAUDIU POPA, FLORINA RUSU
Technical University of Cluj Napoca, Faculty of Machine Building, Department of Mechanical Engineering Systems, 103-105 Muncii Blvd., 400641, Cluj Napoca, Romania

Injected plastic parts with internal threads (round, trapezoidal or saw) can increase products functionality but if not carefully designed can add unforeseen costs into the manufacturing process. In this paper the authors presents a computation methodology of the demolding moment for two cases of plastic injected parts with internal saw thread. This key parameter of the injection process directly influences the design solution of the ejector system. As further work the author will try to validate this method through a set of practical experiments.

Keywords: injection molding, demolding moment, saw thread

Injection molding is the most popular manufacturing process for mass production of plastic parts with simply or complicated geometry. It is known that there are three key phases (i.e. injection, cooling and ejection) during the injection mold process which determines the cost-effectiveness of the plastic product. When the first two sequences are finished and the part is sufficiently cooled the mold is opened. At this moment the part remains on the core of the mold due to the material contraction and also, right before the ejection starts the mold adhesion between the core and the plastic part occurs. The mold adhesion effect has a significant influence on the mold design ejection system and over the selection of the injection process parameters (injected part surface roughness, the properties of the molding material, the dimensioning of actuation devices etc.) even when simply plastic products are considered. Also the adhesion can lead to deformation or cracking [1] of the newly ejected part.

In the technical literature there are a few studies that have paid attention on this problem of adhesion phenomena. Chen and Hwang in [1,2], designed a mechanism for measuring the adhesion force between the sample and the tool surface during the thermoplastic injection molding process. An interesting study about the influence of injection process parameters over the adhesion force is described by Chang in [3]. Pouzada et al. in [4] presented a research on the static coefficient of friction in molding conditions and also reviews some results obtained with a prototype apparatus that reproduces the conditions occurring during the ejection phase. In [5], Pontes and Pouzada investigated the ejection force for deep tubular moldings using three common thermoplastic polymers. Sasakia et al. [6] concluded that the ejection forces increase contrary in the area of surface roughness is less than 0.2 ìm. Dearnley [7] has shown that magnetron sputtered CrN layers applied to polished P20 low alloy steel injection mold, causes a significant reduction in the frictional forces that act during the ejection of an acetal polymer test ring. Wang [8] is proposed a numerical approach to predict the ejection force from the mold-part constraining and friction forces as the product cools in the mold cavity up to the moment of ejection. Haragas et al. [9] developed a theoretical model obtaining the mathematical expression of the demolding force in the case of thin-wall injected parts.

As it can be observed from the above short technical review almost all the authors dealt with this important subject (i.e. mold adhesion) only by the means of experimental researches. Furthermore, the injected parts have tubular shapes.

In this paper, the authors considered a specific injecting molding design problem for two complex parts: 1) – a tubular internal saw threated part; and 2) – a bottle cap (having also a saw profile for the internal thread). In these cases when the injected part is threated the complexity of the ejection system increases and to remove the part as soon as the mold opens the part will be unscrewed from the mold, when a demolding moment occurs.

In here we described a new theoretical methodology for computing the demolding moment for the two injected plastic part with thread, which has a great impact over the design of the ejection system and on the overall dimensions of the mold. As further work we will try to validate ours mathematical expressions of the demolding moment.

In the following section we shall describe in detail the mold and, followed, by a discussion (section 3) regarding the geometry of the injected threated parts and the calculation of the demolding moment for the injected parts with internal saw thread. We conclude the discussion with reflections on possible extensions of the study, as well as possible implications in other areas of engineering design.

The injection mold

The thread with round profile is mainly used in the case of plastic injected parts with thread. However, there are situations in which the thread profile is trapezoidal or saw. For the manufacture of these plastic parts, the molds with mechanical unscrewing of the threaded core (for parts with internal thread) or cavity (for parts with external thread) are used. The rotation motion of the threaded core (or mold cavity) is performed using a spur gearing driven by a multiple-threaded power screw.

An example of this type of injection mold, for injecting plastic part with internal thread (i.e. bottle cap) is presented in figure 1.

The package of plates positioned on the left of the separation plane I-I represents the mobile part of the injection mold. The screw 4 from the fixed plate 10 it is

* *email: Ovidiu.Buiga@omt.utcluj.ro*

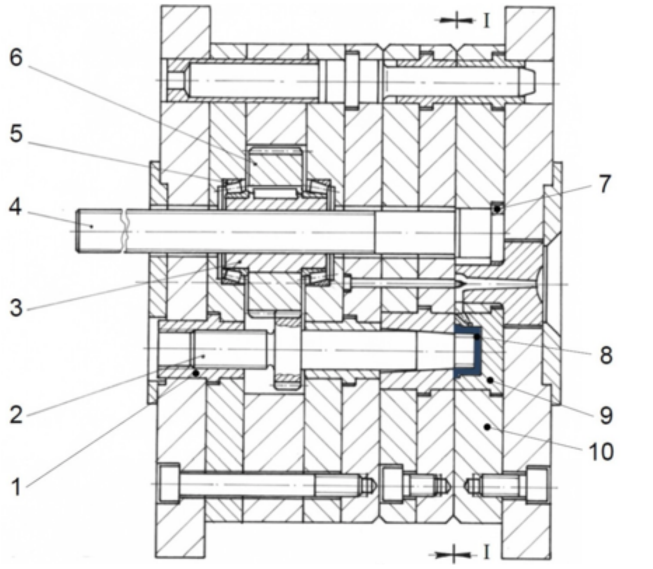

Fig.1 Mold with mechanical unscrewing
1 - threaded sleeve; 2 - threaded core; 3 - nut; 4 - drive screw; 5 - tapered roller bearing; 6 - spur gear; 7 - key; 8 - injected plastic part (i.e. bottle cap); 9 - nicked-sleeve; 10 - fixed plate

prevented from rotating (by the key 7). In this way it is at rest throughout the entire injection process. At the opening of the mold, the nut 3, incorporated in its mobile plate, is bound to execute a translation together with it and, due to the fact that there is no self-braking, the nut will also perform a rotation motion, together with the gear 6. The spur gear 6 meshes with the gear on the threaded core 2, determining it to perform a roto-translation, due to its screwing in the threaded sleeve 1. The thread pitch of the threaded sleeve 1 is the same with the thread pitch of the injected part. The drive screw 4 is multi-threaded. Therefore, the helix lead is large enough to avoid self-braking. The screw is left-handed (LH) one. The nut 3 is supported by the tapered roller bearings 5, which have the purpose of taking over the axial force resulted during the opening or closing of the injection mold.

The theoretical model for the demolding moment

When designing the ejection system for such an injection mold (fig. 1) several factors have to be considered, for example the number of cavities, the demolding moment (necessary to detach the injected part from the mold – computed as a function of the demolding force and of the dimensions of the injected part)**,** the cooling system etc. According to [10] the demolding force is:

$$F_D = \mu \cdot p \cdot A \tag{1}$$

where:μ is the coefficient of friction between the injected part and the core mold. It depends on the plastic injected material and on the processing quality of the active surfaces of the mold; *p* represents the contact pressure between the part and the core; *A* is the contact area between the part and the core.

The pressure *p* is determined from the relation [10]:

$$p = E_{(T)} \cdot \varepsilon_{(T)} \cdot \frac{h}{\rho} \tag{2}$$

where:

$E_{(T)}$ is 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 the wall thickness of the injected part;

ρ is curvature radius of the profile.

Now when the demolding force and the pressure are known in the following subsection, starting from the geometry of the two samples i.e. *the tubular injected plastic part with internal saw thread* (fig. 2) and the *bottle cap* (fig. 3) we will describe the necessary steps and mathematical expressions for determine the demolding moment.

The demolding moment for the case of tubular injected plastic part with internal saw thread

The geometry of the injected part with internal saw thread, considered in this paper is shown in figure 2.

According to the thread pitch, four sections with the widths b_1, b_2, b_3 and b_4 are considered. All the quantities are expressed as a function of the main dimensions: the mean diameter d_2, the thread pitch *P*, the length of the part *L,* and the thickness *h* of the part wall.

The height of the thread is:

$$H_1 = \frac{3}{4} \cdot P \tag{3}$$

and the diameters:

$$D = d_2 + \frac{3}{4} \cdot P \tag{4}$$

$$D_1 = d_2 - \frac{3}{4} \cdot P \tag{5}$$

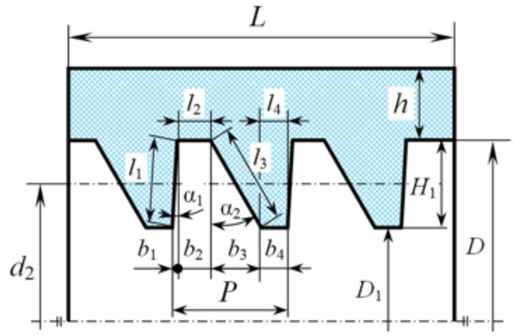

Fig.2 Injected part with internal saw thread

For the saw thread α_1=3°, α_2=30°. The dimensions b_1, b_2, b_3, b_4, respectively l_1, l_2, l_3, l_4 corresponding to the four sections (fig. 2) are calculated using the equations:

$$b_1 = \frac{3}{4} \cdot P \cdot \tan\alpha_1 = 0.03931 \cdot P \tag{6}$$

$$b_2 = 0.26384 \cdot P \tag{7}$$

$$b_3 = \frac{3}{4} \cdot P \cdot \tan\alpha_2 = 0.43301 \cdot P \tag{8}$$

$$b_4 = 0.26384 \cdot P \tag{9}$$

$$l_1 = \frac{H_1}{\cos\alpha_1} = \frac{\frac{3}{4} \cdot P}{\cos\alpha_1} = 0.75103 \cdot P \tag{10}$$

$$l_2 = b_2 = 0.26384 \cdot P \tag{11}$$

$$l_3 = \frac{H_1}{\sin\alpha_2} = \frac{\frac{3}{4} \cdot P}{\cos\alpha_2} = 0.86603 \cdot P \tag{12}$$

$$l_4 = b_4 = 0.26384 \cdot P \tag{13}$$

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

$$y_1 = y_3 = z \cdot \sqrt{(\pi \cdot d_2)^2 + P^2} = \frac{L}{P} \cdot \sqrt{(\pi \cdot d_2)^2 + P^2} \tag{14}$$

$$y_2 = z \cdot \sqrt{(\pi \cdot D)^2 + P^2} = \frac{L}{P} \cdot \sqrt{\pi^2 \cdot \left(d_2 + \frac{3}{4} \cdot P\right)^2 + P^2} \qquad (15)$$

$$y_4 = z \cdot \sqrt{(\pi \cdot D_1)^2 + P^2} = \frac{L}{P} \cdot \sqrt{\pi^2 \cdot \left(d_2 - \frac{3}{4} \cdot P\right)^2 + P^2} \qquad (16)$$

where: z is the number of spires ($z = L/P$).

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

$$A_1 = l_1 \cdot y_1 = 0.75103 \cdot L \cdot \sqrt{(\pi \cdot d_2)^2 + P^2} \qquad (17)$$

$$A_2 = l_2 \cdot y_2 = 0{,}26384 \cdot L \cdot \sqrt{\pi^2 \cdot \left(d_2 + \frac{3}{4} \cdot P\right)^2 + P^2} \qquad (18)$$

$$A_3 = l_3 \cdot y_3 = 0.86603 \cdot L \cdot \sqrt{(\pi \cdot d_2)^2 + P^2} \qquad (19)$$

$$A_4 = l_4 \cdot y_4 = 0.26384 \cdot L \cdot \sqrt{\pi^2 \cdot \left(d_2 - \frac{3}{4} \cdot P\right)^2 + P^2} \qquad (20)$$

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

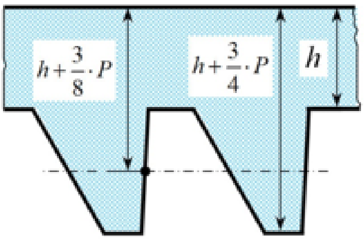

Fig.3 The thicknesses of the part walls

The pressures:

$$p_1 = E_{(T)} \cdot \varepsilon_{(T)} \cdot \frac{h + \frac{3}{8} \cdot P}{\frac{d_2}{2 \cdot \sin \alpha_1}} = 0.05234 \cdot E_{(T)} \cdot \varepsilon_{(T)} \cdot \frac{2 \cdot h + \frac{3}{4} \cdot P}{d_2} \qquad (21)$$

$$p_2 = E_{(T)} \cdot \varepsilon_{(T)} \cdot \frac{h}{\frac{D}{2}} = E_{(T)} \cdot \varepsilon_{(T)} \cdot \frac{2 \cdot h}{d_2 + \frac{3}{4} \cdot P} \qquad (22)$$

$$p_3 = E_{(T)} \cdot \varepsilon_{(T)} \cdot \frac{h + \frac{3}{8} \cdot P}{\frac{d_2}{2 \cdot \sin \alpha_2}} = 0.5 \cdot E_{(T)} \cdot \varepsilon_{(T)} \cdot \frac{2 \cdot h + \frac{3}{4} \cdot P}{d_2} \qquad (23)$$

$$p_4 = E_{(T)} \cdot \varepsilon_{(T)} \cdot \frac{h + \frac{3}{4} \cdot P}{\frac{D_1}{2}} = E_{(T)} \cdot \varepsilon_{(T)} \cdot \frac{2 \cdot h + \frac{3}{2} P}{d_2 - \frac{3}{4} \cdot P} \qquad (24)$$

From (1), (17), (18), (19), (20), (21), (22), (23), and (24) the equations for the demolding forces result:

$$F_{D1} = \mu \cdot p_1 \cdot A_1 = \mu \cdot E_{(T)} \cdot \varepsilon_{(T)} \cdot 0.03931 \cdot L \cdot \frac{2 \cdot h + \frac{3}{4} \cdot P}{d_2} \cdot \sqrt{(\pi \cdot d_2)^2 + P^2} \qquad (25)$$

$$F_{D2} = \mu \cdot p_2 \cdot A_2 = \mu \cdot E_{(T)} \cdot \varepsilon_{(T)} \cdot 0.26384 \cdot L \cdot \frac{2 \cdot h}{d_2 + \frac{3}{4} \cdot P} \cdot \sqrt{\pi^2 \cdot \left(d_2 + \frac{3}{4} \cdot P\right)^2 + P^2} \qquad (26)$$

$$F_{D3} = \mu \cdot p_3 \cdot A_3 = \mu \cdot E_{(T)} \cdot \varepsilon_{(T)} \cdot 0.43302 \cdot L \cdot \frac{2 \cdot h + \frac{3}{4} \cdot P}{d_2} \cdot \sqrt{(\pi \cdot d_2)^2 + P^2} \qquad (27)$$

$$F_{D4} = \mu \cdot p_4 \cdot A_4 = \mu \cdot E_{(T)} \cdot \varepsilon_{(T)} \cdot 0.26384 \cdot L \cdot \frac{2 \cdot h + \frac{3}{2} P}{d_2 - \frac{3}{4} \cdot P} \cdot \sqrt{\pi^2 \cdot \left(d_2 - \frac{3}{4} \cdot P\right)^2 + P^2} \qquad (28)$$

The demolding moment is:

$$M_D = M_{D1} + M_{D2} + M_{D3} + M_{D4} \qquad (29)$$

$$M_{D1} = F_{D1} \cdot \frac{d_2}{2} = 0.01966 \cdot \mu \cdot E_{(T)} \cdot \varepsilon_{(T)} \cdot L \cdot \left(2 \cdot h + \frac{3}{4} \cdot P\right) \cdot \sqrt{(\pi \cdot d_2)^2 + P^2} \qquad (30)$$

$$M_{D2} = F_{D2} \cdot \frac{d_2 + \frac{3}{4} \cdot P}{2} = 0.26384 \cdot \mu \cdot E_{(T)} \cdot \varepsilon_{(T)} \cdot L \cdot h \cdot \sqrt{\pi^2 \cdot \left(d_2 + \frac{3}{4} \cdot P\right)^2 + P^2} \qquad (31)$$

$$M_{D3} = F_{D3} \cdot \frac{d_2}{2} = 0.21651 \cdot \mu \cdot E_{(T)} \cdot \varepsilon_{(T)} \cdot L \cdot \left(2 \cdot h + \frac{3}{4} \cdot P\right) \cdot \sqrt{(\pi \cdot d_2)^2 + P^2} \qquad (32)$$

$$M_{D4} = F_{D4} \cdot \frac{d_2 - \frac{3}{4} \cdot P}{2} = 0.26384 \cdot \mu \cdot E_{(T)} \cdot \varepsilon_{(T)} \cdot L \cdot \left(h + \frac{3}{4} \cdot P\right) \cdot \sqrt{\pi^2 \cdot \left(d_2 - \frac{3}{4} \cdot P\right)^2 + P^2} \qquad (33)$$

From the equations (29), (30), (31), (32), and (33) it results:

$$M_D = \mu \cdot E_{(T)} \cdot \varepsilon_{(T)} \cdot L \cdot \{0.23617 \cdot (2 \cdot h + 3/4 \cdot P) \cdot \sqrt{(\pi \cdot d_2)^2 + P^2} + 0.26384 \cdot [h \cdot \sqrt{\pi^2 \cdot (d_2 + 3/4 \cdot P)^2 + P^2} + (h + 3/4 \cdot P) \cdot \sqrt{\pi^2 \cdot (d_2 - 3/4 \cdot P)^2 + P^2}]\}$$

$$M_D \cong 0.25 \cdot \mu \cdot E_{(T)} \cdot \varepsilon_{(T)} \cdot \pi \cdot L \cdot [(2 \cdot h + 3/4 \cdot P) \cdot \sqrt{d_2^2 + (P/\pi)^2} + h \cdot \sqrt{(d_2 + 3/4 \cdot P)^2 + (P/\pi)^2} + (h + 3/4 \cdot P) \cdot \sqrt{(d_2 - 3/4 \cdot P)^2 + (P/\pi)^2}] \qquad (35)$$

Using the equation (35) the demolding moment for a plastic injected part with internal saw thread can be calculated in the design phase of the mold.

The demolding moment for the case of a bottle cap

If the part is closed at one of its ends (fig. 4 – a bottle cap) the demolding moment is given by:

$$M_{D\,tot} = M_D + M_{DC} \qquad (36)$$

where: M_{DC} is the demolding moment necessary to detach the end of the part.

$$M_{DC} = \frac{1}{3} \cdot \mu \cdot \frac{\pi \cdot \left(d_2 + \frac{1}{2} \cdot P + 2 \cdot a_c \right)^3}{4} \cdot p_n \qquad (37)$$

where: p_n is the negative pressure (p_n = 0.1 MPa).

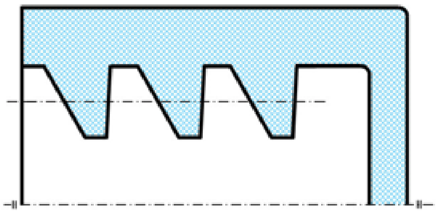

Fig.4. Injected part with internal saw thread closed at one of its ends (bottle cap)

Conclusions

Adding molded threads to your plastic part design can increase parts functionality but if not carefully designed can add unforeseen costs into the manufacturing process. In here, the authors presented a methodology for theoretical determination of the demolding moment M_D which can be calculated if the material, technological parameters, and the geometric dimensions of the injected parts are known. This parameter represents a key factor (the magnitude of this moment directly influences the design solution of the ejector system) for a mold design without supplementary costs. As further work the author will try to validate this method through a set of practical experiments.

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