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Tools for the Production of Plastic Products

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Abstract*: The paper discusses the types of system elements of mold parts. The calculation method of design data tooling which can be used at design of injection mold is offered. This method gives the chance to provide the necessary accuracy of casting. Distinctive feature of the offered method is modification of the formalized shrinkage material description of a molding detail. The offered calculation method of design data tooling allows increasing the accuracy of the received plastic product because are considered: absolute and relative volume shrinkage; relative actual linear shrinkage of material; alleged linear shrinkage.

Keywords*: Injection Mold, Mold Details, Durability, Accuracy, Shrinkage, Plastic.

I. INTRODUCTION

The development of plastic products production involves a constant increase in the technological tooling (injection molds – IM, mold). The most widely used method of plastic production is the technology of injection plastics under pressure (IPUP) [1]–[4].

Form for injection of plastics under pressure (tooling) is the main element that governs the design and quality of finished plastic products.

At the same time, the design of IM can be divided into the following main systems: system of placing, installing and securing injection molds; system of the mold details (MD); system of centering; cooling system and temperature regulations of a form; the removal system of products from forms; system of details movement [2], [5].

An essential role at design of IM is played by the system of the mold details, which at the closed semi-forms form the mold cavity (MC).

The configuration of details of this system has to provide the optimum duration of a cycle, high-quality filling of a cavity, extraction and colliding of products. Therefore the problem of quality improvement at design of the tooling takes the important place in the course of production of any products. The successful solution of this task can be also reached thanks to the MD rational sizes.

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Exact calculation of design MD data of the tooling is for this purpose necessary.

II. MATERIALS AND METHODS

A. A brief review on the topic of the study

An article by R. Geyer J. R. Jambeck and K. L. Law analyzes the production of plastic products [6]. The authors pay special attention to new technologies that are able to establish the production of parts with the necessary parameters. Attention is also paid to recycling methods for plastic products that have exhausted their useful life.

S. Jayswal, H. Jangade, K. Abhishek and P. L. Ramkumar distinguish IM from tools for the production of plastic products [7]. Therefore, special attention is paid to the geometry of IM. This is the main task, which is able to ensure the release of the necessary product.

The geometry of IM is the basis of the study of G. A. Mendible, J. A. Rulander and S. P. Johnston [8]. The authors consider fast methods for analyzing the geometry of IM. If necessary, an adjustment is made to the manufacturing process of plastic products.

O. Murodov in his work analyzes the effectiveness of the use of plastic products [9]. This product is plastic grates in cotton cleaners. O. Murodov concludes the importance of the shape and dimensions of a plastic product during their operation.

Thus, IM geometry plays an important role in the manufacture of plastic products. At the same time it is necessary to consider features of mold details.

B. Features of the mold details

The most important characteristic of IM is her system of the mold details as she directly influences quality of the made products. The mold details (matrixes, punches, signs, plates, etc.) are structurally diverse as their contours and the sizes negatively repeat geometrical features of a product. It is necessary to refer to the main signs on which distinguish the mold details [10]:

- interrelations with other details of a form – one-piece, clip-on and compound designs;
- a gateable – for the single-gates and the multiple gates of forms;
- a class of products accuracy – for ordinary (the 4-7th class) and precision (the 2-3rd class);
- character of the mold cavity – for smooth products, products with undercuts, threaded connections and opaque and other decorative surfaces;
- a way of movement – moving automatically, moving in cartridges, removable, replaceable in stationary and removable forms;
- the number of fusion flowers – for one-color casting,

multi-color casting to accurate differentiation for about several flowers the universal cars working is coupled or by one special car and also multi-color casting to indistinct differentiation of flowers;

- a geometrical form of products – flat and volume, round, conical and rectangular articles, tubular and ring products, case, gear and slitting products;

- on manufacturing techniques – produced by mechanoprocessing, cold expression, an electrospark way and electrodeposition of the nickelcobalt and nickel.

Basic elements of MD are punches and matrixes [11], [12]. On the design they are also rather various. This variety is generally caused by design features of IM, a product design and also technological ways features of their receiving.

Taking these features into account is important for maintaining IM geometry. This is reflected in the general scheme for calculating IM sizes.

C. General steps in design the mold details of injection molds

The mold details of injection molds under pressure in the course of their designing count:

- the executive sizes of those elements which surfaces participate in formation of products;

- durability's of separate elements and detail in general;

- accuracy of assembly and her preservation at operation, ensuring definiteness of details landings in holders, plates, etc.

All MD elements which adjoin to fusion and participate directly in formation (injection) of the plastic product corresponding to them elements, have to be executed so that the set quality parameters, sizes accuracy of a product (in all program of release) certainly have been provided, despite the shrinkage and fluctuation of shrinkage of material (which are shown at formation of a product), inaccuracy of production and details attrition of a form during her operation. Therefore at design of all MD, during development of their working drawings, count such executive sizes, compensating possible fluctuations and changes in their sizes.

Calculations of durability of a punch and matrixes of forms carry out for determination of rational walls thickness. Calculations of durability are complemented with calculations of especially loaded details deformations. The basic parameter regulating results of strength and deformation calculations in forms is injection pressure of fusion in a form under the influence of which in the mold details tension leading to deformations or – in emergencies – to destruction of details on their dangerous sections develops. Such calculations carry out by the known methods resistance of materials [1], [2]. At design of the MD test calculation on durability and deformability should be carried out for one-piece and compound (round and rectangular) holders of matrixes.

Calculations (or justification of the landings choice, especially with a tightness) carry out traditionally by the methods based on the theory of admissions and landings [1], [2]. Such calculations bring when designing combined punches and matrixes when inserts or other details are pressed with a tightness one in another.

At the same time it is especially important to estimate the arising deformations of those surfaces (elements) of punches and matrixes which directly form a product (values of these deformations shouldn't exceed the requirements established by qualitative parameters of products).

Differences in results of calculation for different methods can be noticeable. Basing on the extreme sizes of a product leads to the fact that the wear of the mold details doesn't remove the sizes of products for limits of the set admissions, but sizes distribution is unevenly displaced across the field of the admission to these limit borders that in general is less favorable, than at base – the average size.

Results of executive sizes calculation of the mold details anyway need to be rounded ("covering" – towards increase, "covered, interaxal, high-rise" – reduction) with the frequency rate depending on the finish and the size of the nominal detail size.

Thus, as the main calculation tools for the manufacture of plastic products are:

determination of product thickness;

calculation of the core diameter size;

calculation of shrinkage;

calculation of product strength by adjusting its wall thickness.

III. RESULTS AND DISCUSSION

At production of plastic products it is necessary to calculate the sizes of the mold details of the form-building equipment. Nevertheless, the calculation methods now existing use information on shrinkage of initial material insufficiently. For plastic details, considering the considerable, unstable shrinkage changing in use details that can lead to big errors in this regard improvement of calculation methods is relevant for increase in vital firmness of products including maintainability (collecting) when carrying out scheduled maintenance. At the same time the configuration of MD system has to provide the optimum duration of a cycle, high-quality filling of a cavity, extraction and colliding of products. The details design of this system generally is defined by the nature of mold cavity filling. Therefore the MD executive sizes define depending on the admission on the sizes of a detail and shrinkage of forming material [1]. We will consider the settlement model of the matrix sizes for production of a detail from plastic (Fig. 1, a) [2]:

$$D_m = D_{max} + D_{max} \cdot 0{,}01 S_{max} - T_{pr}, \qquad (1)$$

where:

D_{max} – maximum diameter of a product;

S_{max} – maximum shrinkage of plastic, %;

T_{pr} – admission on the product size.

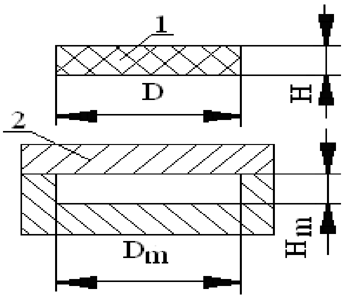
$$H_m = H_{max} + H_{max} \cdot 0{,}01 S_{av} - 0{,}5(T_{pr} + T_{MD}), \qquad (2)$$

where:

H_{max} – maximum thickness of a product;

S_{av} – average shrinkage of plastic, %;

T_{MD} – admission on the size of the mold detail [2].



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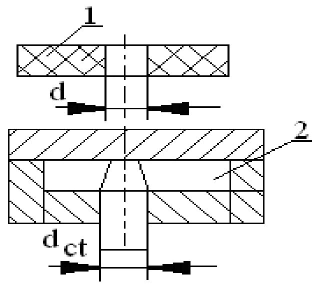


b)

Fig. 1. The scheme of the making-out details: a) detail and matrix; b) mold knot (1 – detail, 2 – matrix).

The principle of the detail sizes calculation and the mold knot can be presented in Fig. 1, b. Calculation of the core diameter size (the mold sign) is perfromed on a formula

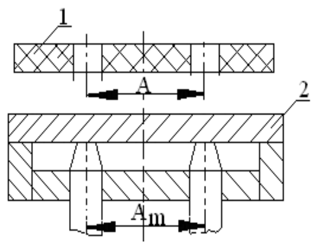
$$d_{CR} = d_{min} + d_{min} \cdot 0{,}01 S_{min} + T_{pr}, \qquad (3)$$

where:

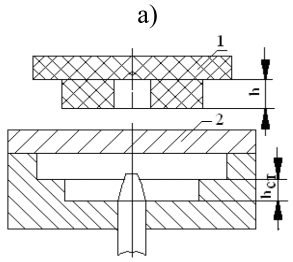
d_{min} – minimum boundary size of an opening in a detail;

S_{min} – minimum shrinkage of a product, %.

As an example of the reviewed method we will calculate distance of a detail 1 and the mold element 2 between centers (Fig. 2, a) and also we will find height of the core presented in Fig. 2, b [2].



a)



b)

Fig. 2. The scheme of a detail 1 and the mold element 2
a) distance between centers; b) core height.

The distance equals between centers

$$A_m = A + A \cdot 0{,}01\ S_{av}. \qquad (4)$$

We find height of a core on a formula

$$h_{cr} = h_{min} + h_{min} \cdot 0{,}01 S_{cav} + 0{,}5(T_{pr} + T_m), \qquad (5)$$

where h_{min} – minimum boundary size of a product.

In the course of injection the product in shape accepts outlines and the MC sizes. In time and after filling and consolidation there is a cooling of a product. It proceeds at his extraction from a matrix colliding from a punch and after his extraction from a form. Owing to cooling the volume of a product decreases, and eventually the product has to get a certain form and the sizes in the set limits. Since each surface element of a product decreases, at design the size of this element on MD has to be more set. This difference is also shrinkage. Shrinkage when calculating is chosen according to standards and specifications on product material.

The absolute volume shrinkage defined after the termination of shrinkage can be calculated by a formula [1]

$$\Delta V = \sum_{i=1}^{n} \Delta V_i, \qquad (6)$$

where:

ΔV_i – absolute shrinkage of detail structural elements.

ΔV_i is function $f(X_i, Y_i)$,

X_i – set of design data of i-th element,

Y_i – set of shrinkable properties of material of which i-th element consists.

Then

$$\Delta V_i = \iint_{G_i} \ldots \int f(X_i, Y_i) dx_1^i dx_2^i dx_m^i dy_1^i dy_2^i dy_q^i, \qquad (7)$$

where G_i – range of definition X_i, Y_i.

It is easy to define relative volume shrinkage by these expressions

$$\Delta V_{REL} = \Delta V \cdot V_{Pr}^{-1}, \%, \qquad (8)$$

where V_{Pr}^{-1} – product volume.

We find the absolute actual linear shrinkage defined after the termination of shrinkage on a formula [1]

$$\Delta l = \sum_{i=1}^{n} \Delta l_i, \qquad (9)$$

where:

Δl_i – absolute linear shrinkage of structural elements of a detail is also function $\beta(X_i, Y_i)$,

X_i – set of design data of i-th element,

Y_i – set of shrinkable material properties of which i-th element consists.

Then

$$\Delta l_i = \iint_{G_i} \ldots \int \beta(X_i, Y_i) dx_1^i dx_2^i dx_m^i dy_1^i dy_2^i dy_q^i, \qquad (10)$$

where G_i – definition range X_i, Y_i.

From here we define relative linear shrinkage

$$\Delta l_{REL} = \Delta l \cdot l_{Pr}^{-1}, \%. \quad (11)$$

Relative actual linear shrinkage can be determined by a formula

$$x_{RL} = (l_{MD} - l_{Pr}) l_{Pr}^{-1} \cdot 100, \%. \quad (12)$$

Alleged linear shrinkage:

$$x_{AL} = (l_{MD} - l_{AV}) l_{AV}^{-1} \cdot 100, \%, \quad (13)$$

where:

l_{AV} – the nominal size of an element detail at a symmetric arrangement of a tolerance zone (at 20 °C).

Having solved (19) is relative l_{MD} (or L_{MD}), we will receive two basic formulas (20) and (21) by which the sizes of all MD are calculated. For the elements which are making out external surfaces of a product

$$L_{MD} = [L_{AV}(1 + x_{AL}/100) - \Delta_{ATT}]^{+\Delta_{ADM}}, \quad (14)$$

for the elements which are mold internal surfaces of a product

$$l_{MD} = [l_{AV}(1 + x_{AL}/100) + \Delta_{ATT}]_{-\Delta_{ADM}}, \quad (15)$$

where:

Δ_{ATT} – the set attrition of the MC element during operation of a form, mm; depending on the admission of a product and the nature of production it is accepted by 0,02 ÷ 0,20 mm;

Δ_{ADM} – admission on production of the MC element L_{MD} and l_{MD}; usually has to be higher on 1 – 2 class than the admission on the product size.

After calculation of shrinkage it is necessary to determine durability of the made product by adjustment of its walls thickness. As durability of a plastic product isn't equal to plastic durability. Also durability, uniformity of shrinkage, that is, the accuracy of the product depends sizes on the nature of flowing fusion in a cavity.

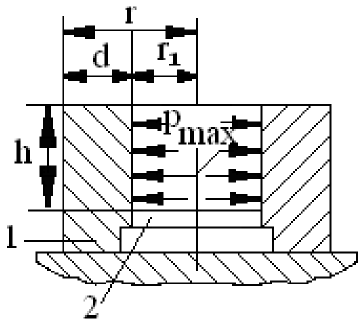
In molding forms pressure changes from 0 to p_{max} in closed provisions of a form that demands calculation of walls thickness taking into account instability of material shrinkage. For him are initial: p_{max} configuration of a cavity and matrix material. For a round matrix 1 (Fig. 3, a) wall thickness decides on a plug-in bottom from conditions $(r - r_1) + \Delta l$:

$$p_{max} 2 r_1 h = 2(r - r_1) h\sigma + \varphi(\Delta V) \text{ and } (r - r_1) = p_{max} r_1 \sigma^{-1}.$$

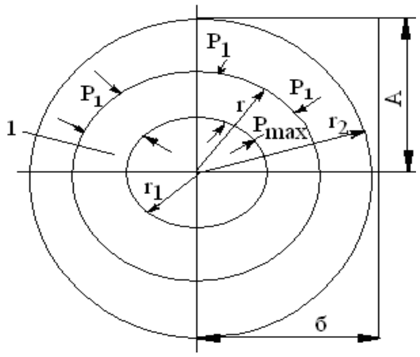
where:

p_{max} – maximum pressure in shape;

$\varphi(\Delta V)$ – the amendment caused by volume shrinkage ΔV, defined by functional modeling of the equipment.



a)



b)

Fig. 3. Scheme configuration of a round matrix: a, b) dependence of wall thickness on a design of matrixes.

For especially loaded matrixes where increase in wall thickness doesn't lead to reduction of tension by surfaces of MC, a matrix are pressed in holders with a tightness δ. In these designs called by the fastened cylinders in a matrix 1 (Fig. 3, b) the squeezing tension p_1 which reduce σ, caused by influence arises p_{max}. It allows to allow when calculating, $\sigma_{зап}$ higher, than σ for not pressed matrixes. If material of a holder and matrix equally works for stretching and compression, external radius of a holder $r_2 = r^2/r_1$, mm, a tightness $\delta = 2rp_{max}/E$, then tension in the pressed matrix $\sigma_{зап} = m\sigma$, Pa.

Coefficient m always more unit is also equal $m = 2/(1 + K)$ where $K = r_1/r_2$ [2]. So, at $K = 0{,}5$ $m = 2/(1 + 0{,}5) = 1{,}33$, that is $\sigma_{зап}$, there is more stretching tension for 33% that allows to project more compact designs.

Thus, at production of plastic details, having considered the considerable, unstable shrinkage changing in use details it is possible to avoid some errors, in this regard the calculation method of the mold details of the tooling taking into account shrinkage is offered that will provide increases in vital firmness of radio-electronic equipment.

The developed method differs from existing, what considers all features of plastic material shrinkage.

We can also determine the general sequence of actions for calculating the design parameters of technological equipment in the manufacture of injection molds of plastic products:

1. To define the set attrition of the MC element during operation of a form.

2. To determine the admission on production of the MC elements.

3. To define absolute volume plastic material shrinkage of a product .

4. To define relative volume plastic material shrinkage of a product .

5. To define relative actual linear plastic material shrinkage of a product.

6. To define alleged linear plastic material shrinkage of a product.

7. To determine the MD executive sizes.

This distinguishes the above study in particular from the works [6]-[8].

At the same time, we expanded the possibilities of calculating the shrinkage of a plastic product, which distinguishes our work from research [13], [14]. But we also took into account the main parameters of the effect on shrinkage, which was considered in [14].

We also use methods of mathematical analysis to calculate shrinkage, unlike the study [15], where optimization methods are used.

Nevertheless, the proposed tools for calculating forms for the manufacture of plastic products can minimize possible errors and get high-quality products. In particular, we can model our products as described in [16].

IV. CONCLUSIONS

Thus, as each detail requires on the substance of acceptance individual solutions at design of forms, and one of stages is determination of the mold details sizes.

The final size of the form element which is mold a plastic detail – the mold detail, has to be executed at production of a form that at her operation plastic details of the required quality and accuracy were issued.

Accuracy and quality of castings depends first of all on the accuracy of production of IM and the MD sizes.

As a result, the offered calculation method of design data of the tooling can be used at design of IM and gives the chance to provide the necessary accuracy of casting. Distinctive feature of the offered method is modification of the formalized description of material shrinkage of a molding detail.

The offered calculation method of design data of the tooling allows increasing the accuracy of the received plastic product because are considered: absolute and relative volume shrinkage; relative actual linear material shrinkage; alleged linear shrinkage.

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