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Національний університет
харчових технологій
вул. Володимирська, 68
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e-mail: **ufj_nuft@meta.ua**

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Contents

Modeling of extrusion-blown molding process of polymeric package

Oleksandr Sokolskyi[1], Ihor Mikulionok[1],
Oleksandr Gavva[2], Veronica Gromova[1]

1 – National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine
2 – National University of Food Technologies, Kyiv, Ukraine

Abstract

Introduction. For achievement of uniform minimum thickness of a wall of the created container and definition of the corresponding technological modes numerical researches of process of hollow polymeric products formation are conducted. Researches are conducted depending on a form of preparation and a finished product

Material and methods. In this work formation process by blowing of an axisymmetric bottle is modeled. Initial workpiece represents a cylindrical sleeve with an external radius of 10 mm. After creation of internal pressure workpiece is blown, the contact between polymer and a blown form will not be provided yet. The research is conducted on the case of formation of products from a polyethylene with low density (LDPE).

Results and discussion. When the process of blowing the internal pressure is being modeled, initial thickness and outer diameter of preparation are set as constants. With an increase in the radius of a bottom corner of a bottom a wall thickness increases, however at the same time the product becomes unstable. For ensuring the minimum necessary thickness in this place it is necessary to spend excess material in other sections. Extent of thinning of a wall of a product increases with an increase in extent of blowing on a certain local site. As it follows from the results of modeling, for achievement of the minimum necessary uniform thickness of a product it is necessary to change workpiece thickness on height (in this case - to reduce it in the lower and average parts). This method of calculation of a necessary profile of thickness of preparation allows to reach uniformity of thickness of walls of the product. For this purpose workpiece on height breaks into conditional nodes, in each of which the necessary thickness of workpiece depending on the calculated product wall thickness in the corresponding point is defined by iteration.

Conclusion. The interrelation between the workpiece, a finished product and the distribution of thickness in its walls is defined.

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Corresponding author:

Oleksandr Sokolskyi
E-mail:
sokolkiev@ukr.net

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Introduction

Polymeric materials use as raw materials for production of packing materials, such as bottles, flasks, containers, canisters for packing of the wide range of foodstuff and other consumer goods, in particular soft drinks, alcoholic beverages, detergents, cosmetics, pharmaceutical products and food oils.

In the course of extrusion-blown molding process of a polymeric container at first polymeric workpiece forms by extrusion method. Then workpiece moves in a molding tool in which it is blowed by compressed air and takes the form of a final product [1]. Production of various container and canisters from polymeric materials is carried out by method of blowing on extrusion-blown units. All extrusion-blown units include three main components: an extruder, a die and a receiving device which basis is the molding tool for blowing.

Unlike the majority of methods of receiving products of plastic in which formation is carried out from melt in this technology polymer when blowing is exposed to mainly highly elastic deformation [2]. Workpiece which comes out an extruder die in a molding tool is affected by a body weight therefore it is extended. Degree of a blowing of workpiece is non-uniform on height therefore the container turns out with various thickness on height. In modern machines for controlling of thickness of walls of workpiece dies with program regulation which allow to form workpiece with the necessary distribution of thickness of a wall on its height are used. A problem of regulation is achievement of the necessary distribution of thickness of a wall of a finished product. Mathematical solution of the problem it is limited only by separate cases, the trial and error method demands considerable expenses of time. Therefore it is more expedient to use methods of computer modeling.

Within the last decades computer models promoted significant improvement of the analysis of formation processes therefore now they are widely used for process optimization [3-6]. Computer models can minimize undesirable variations of thickness of a wall of a finished product and reduce the weight of a finished product at ensuring of its durability. In spite of the fact that blown formation was used for many years, producers still meet difficulties in optimization and control of process [7]. Nevertheless, there are successful examples of similar glass blow molding process simulation [8].

The purpose of researches is determination of uniform minimum thickness of the wall of the created hollow polymeric products depending on the form of workpiece and a finished product, and also definition of the corresponding technological modes. The specified objectives are achieved by numerical modeling.

Material and methods

Material

The dependences received as a result of the analysis of numerical researches of extrusion-blown molding process of a polymeric container are given in the article. Distribution of thickness of a wall of hollow polymeric products depending on physical and technological parameters is investigated. On the basis of the executed researches the problem of receiving the hollow polymeric products received by extrusion-blown molding process with more uniform thickness of a wall is solved. Researches are executed for formation of products from polyethylene of the low density (LDPE).

In this work blowing process formation of simple 2-D axial-symmetric bottles is modeled. We assume that process single-stage, i.e. formation of workpiece with its subsequent blowing. At the same time the internal pressure as a result of which action workpiece is blown is set, contact between polymer and a molding tool will not be provided yet.

For material necessary following conditions:

– viscosity: $\eta = 2{\cdot}10^5$ Pa·s;

– density: $\rho = 820$ kg·m^{-3}.

Methods

From the geometrical point of view, initial workpiece represents a cylindrical sleeve with an external radius of 10 mm. The general height of a bottle is 150 mm (Figure 1).

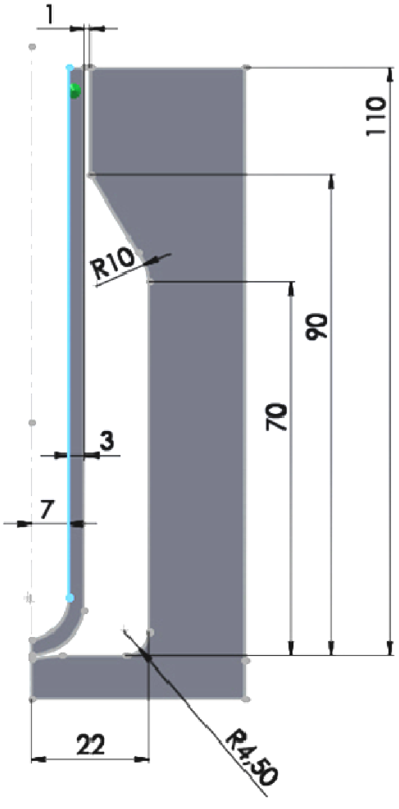

Figure 1. Initial configuration of workpiece and molding tool

The technique of numerical experiment is realized according to recommendations of the developer of an Ansys Polyflow software [9]. The design engineers have used this software to minimize physical prototyping when manufacturing extrusion dies or to reduce thickness variation to improve the quality of thermoformed or blown products [10].

The only working parameter is pressure of blowing P which equals $6{\cdot}10^5$ Pa·s. This pressure is set by normal force. In the given example pressure of blowing does not depend on time. Gravity and inertia is considered. As in the course of blowing the initial form of workpiece is considerably deformed, on each step on time it is necessary to reconstruct net area. Therefore the most expedient is the calculation method on the basis of the "Thin Shell Method + Lagrangian master" method along the main line. The surface which will come under the greatest influence, that is a surface of contact with a form was chosen as the main line.

Control of temporary iterative parameters in accordance with the recommendations [11]:

Initial value of time: 0 s;
Top value of time: 2 s;
Initial value of time for one step: 0.01 s;
Minimum value of time for one step: 0.001 s;
Maximum value of time for one step: 0.05 s;
Maximum quantity of successful steps: 200;
Value of an error on time: 0.01 s.
Control of geometrical iterative parameters:
Correctional coefficient: 10^9;
The admission on penetration: 0.001;
Expansion of an element: 0.001;
Sliding coefficient: 10^9.

Results and discussion

Mathematical model

To formulate a mathematical problem for blown formation, it is necessary to consider various zones of a forming machine, namely zone of air, zone of a form and zone of melt [12–14].

In figure 2 it is shown breakdown of area of a forming machine for axial-symmetric formation.

Area borders: Γ_m is internal border of a form; Γ_o is external border; Γ_f is border melt – air (Γ_1 is internal surface of melt; Γ_2 is external surface of melt); Γ_s is symmetry axis; Ω_a is border of air area; Ω_1 is border of material area.

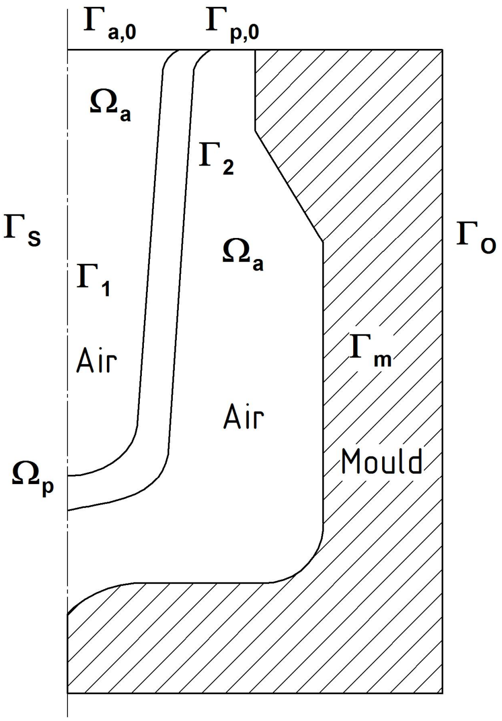

Figure 2. Axial-symmetric area and subareas of a forming machine

For the simplified modeling it is possible to assume that the equipment has constant temperature [15].

The mathematical model is based on conservation laws of mass and an impulse both for the formed material, and for air:

$$\frac{D\rho}{Dt} + \rho\nabla \cdot u = 0, \qquad in\ \Omega \setminus \Gamma_f \times \mathrm{T},$$

$$\rho\frac{Du}{Dt} = \nabla \cdot \tau + \rho g, \qquad in\ \Omega \setminus \Gamma_f \times \mathrm{T},$$

where T is formation process duration, s; u - stream speed, $\mathrm{m \cdot s^{-1}}$; ρ is density, $\mathrm{kg \cdot m^{-3}}$.

The limit of the section melt–air is defined from the usual differential equation

$$\frac{dx}{dt} = u \qquad in\ T,$$

for all $\boldsymbol{x(t)} \in \Gamma(t)$ and any mobile border $\Gamma(t)$.

In the equation of a state (Navier-Stokes) for viscous liquids [16] the tensor of tension is defined as

$$\tau = 2\mu\dot{\varepsilon} - pI,$$

where μ is viscosity, Pa·s; *p* is external pressure, Pa; *I* is single tensor of the second rank; the tensor of deformation speed is defined by derivative of a stream speeds vector

$$\dot{\varepsilon} = \frac{1}{2}\left(\nabla u + u\nabla\right)^{\cdot}$$

Initial conditions include distribution a component of speed and pressure in an initial timepoint in settlement areas.

Boundary conditions for a stream can be defined as follows:

– on Γ_s symmetry conditions are set;

– on $\Gamma_{1,o}$ and $\Gamma_{a,o}$ normal tension has to be to equally external pressure;

– the boundary condition for the description of a stream of liquid on an impenetrable wall is reduced to a sticking condition [17, 18]

$$u = 0, \qquad on\ \Gamma_{1,o} \times T.$$

When modeling blown formation of a bottle from tubular workpiece several variations of process are carried out. At a blowing internal pressure P = 0.6 MPa·s was considered, the initial thickness of workpiece was set by uniform and made 3 mm, the external diameter of workpiece is 10 mm.

Results of modeling

In Figure 3 it is represented wall thickness in various characteristic points of a finished product. Follows from results of modeling that for achievement of minimum necessary uniform thickness of a product it is necessary to change workpiece thickness: in this case to reduce it in the lower and average parts.

When modeling process of blowing of a product with various values of a lower corner of a bottom dependence of thickness of a wall on the product height of which the schedule represented in Figure 4 is result is found.

Figure 3. Distribution of thickness of the product wall at the radius of the lower corner of a bottom of 4.5 mm

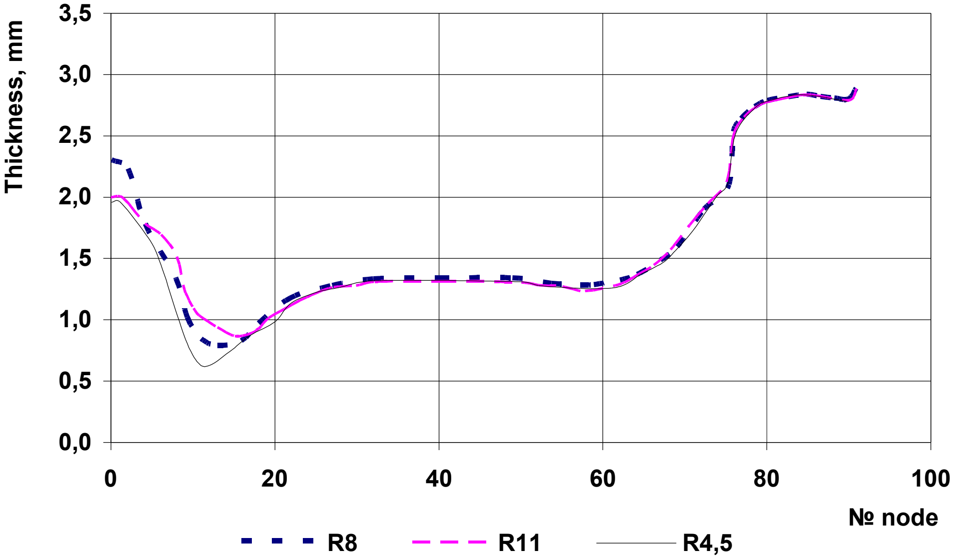

Figure 4. The schedule of dependence of thickness of a product at various values of radius of a bottom

It is obvious that at radiuses of 4.5 and 8 mm thickness of a product is not optimum relatively the product height, and at the radius of 11 mm the product becomes unstable that is caused by rather big radius of a bottom.

For more detailed analysis of blown formation process calculations for various products blowing degree are carried out. In this case degree of blowing depends on diameter of a cavity of a blown form therefore for calculations its various values are chosen. Dependence of the relation of thickness of workpiece to the minimum thickness of a wall of a finished product from extent of blowing it is shown in fig. 5.

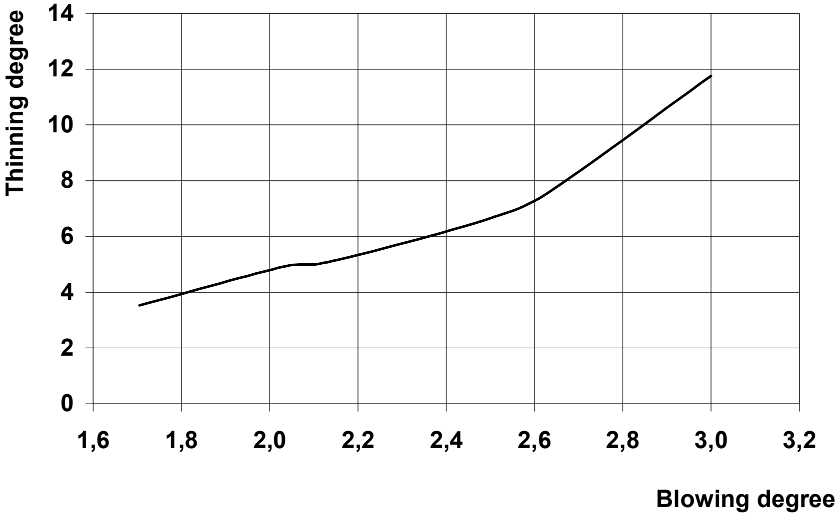

Figure 5. Dependence of thinning degree of a product wall on blowing degree

It is established that distribution of thickness of the container wall at a uniform thickness of workpiece is not optimum as for ensuring minimum necessary thickness in the most weak spot (as a rule, upon transition of a bottom to a wall) in other sections it is necessary to use excess material Therefore we will use the technique given in [9], which can provide the necessary thickness of walls on all height of a product. For this calculation it is used a tool with a radius of a lower corner of a bottom of 4,5 mm.

For each knot of workpiece we will calculate thickness H_i:

$$H_i = H_{i-1} + \alpha\left(\frac{h_c}{h_f} - 1\right)H_{i-1},$$

where $\alpha \approx 0{,}9$ is a relaxation factor; h_c=1 is the set product thickness; h_f is current thickness of a product; H_0=3 is initial thickness.

Having calculated values, we receive distribution of thickness of a product which is represented in fig. 6.

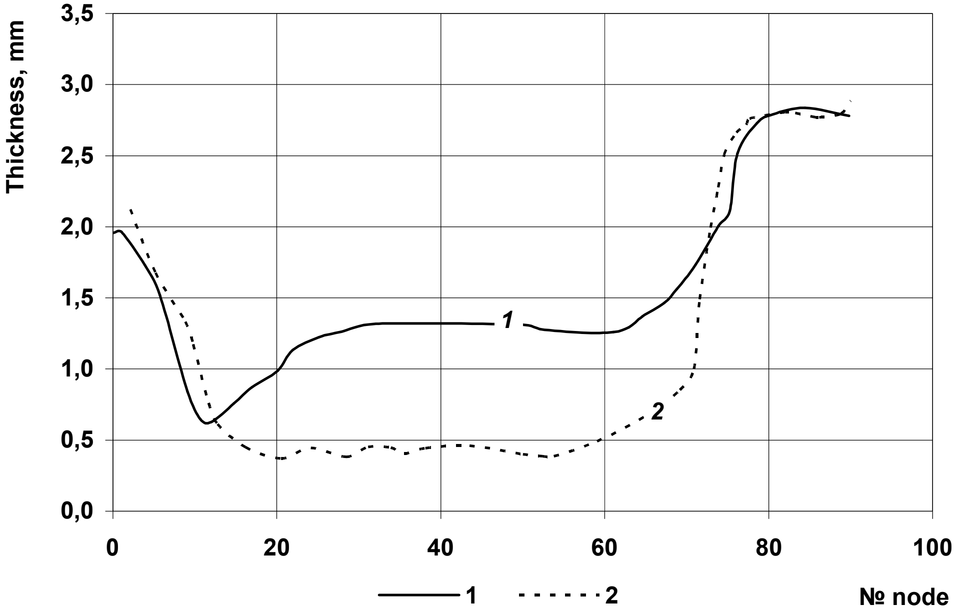

Figure 6. Dependence of thickness on product height:
1 – preliminary; 2 – after application of the techniques

From Figure 6 it is visible that in this example on the most part of height of a product it was succeeded to reach almost identical thickness of the wall.

For check of reliability of the received results comparison of theoretical distribution of thickness of the wall with the valid thickness of the wall of private enterprise "Crystal Glass" bottle with a capacity of 100 ml was carried out.

For comparison of calculated values of thickness of a product to the measured values the schedule which is represented in Figure 7 is constructed.

Thickness of the wall of a real product without a neck and a bottom fluctuates from 0.51 mm to 0.73 mm, and the dispersion of calculated values fluctuates from 0.64 mm to 0.87 mm. Comparison of schedules shows that thanks to a technique of optimization more uniform thickness of the product wall is reached. In the considered case uniformity of thickness of the wall increased to 25 %, and at the subsequent iterations it is possible to reach the best values. The profile of thickness received by calculations is realized at workpiece extrusion by program regulation of size of section of the forming die.

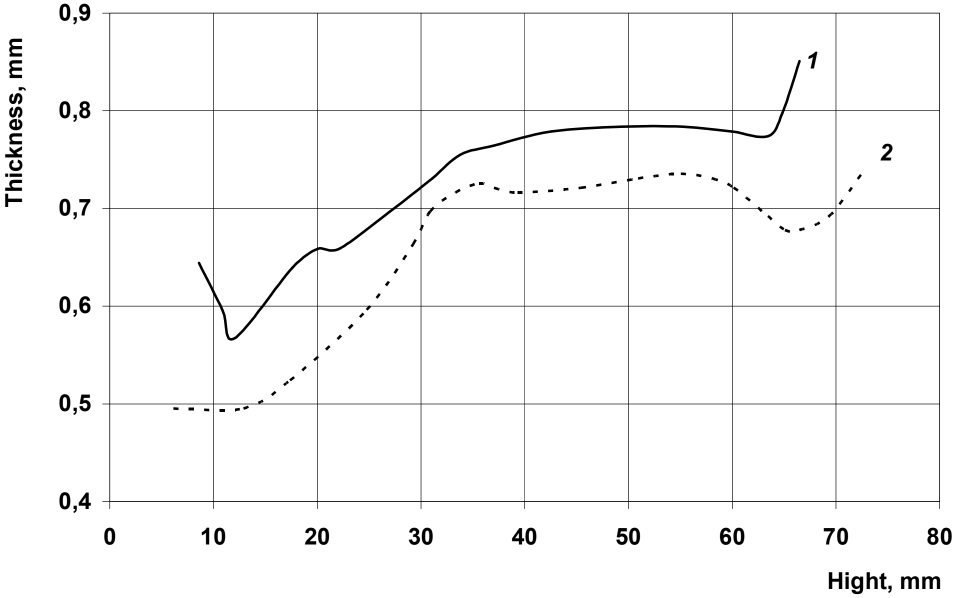

Figure 7. Distribution of thickness of the bottle walls
1 – calculated values; 2 – measured values.

Conclusion

Research of workpiece walls thickness at various initial parameters of extrusion-blown molding process of polymeric package is conducted.

The given technique of calculation of necessary of workpiece walls thickness wall allows to reach uniformity of product walls thickness. It is expedient to use this technique for production of hollow products by extrusion-blown molding method.

Further authors similarly assume to improve various hollow polymeric products and to introduce a technique of program calculation of workpiece thickness at the enterprises of the packing industry.

The interrelation between the workpiece, a finished product and distribution of thickness of its walls is defined.

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