Model of preform deflected mode in the process of secondary polymer materials coextrusion processing

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Abstract. The paper analyzes the topicality of secondary polymer materials usage in new products. It considers the main stages of secondary polymers processing. Three main groups of recycling processes are singled out, i.e. preparatory, shape-generating, and auxiliary. The paper highlights special perspectives of the coextrusion with further blowing technology usage. The calculation of multilayer preform adhesion for different loading conditions is done. The paper researches the deflected mode in the process of blowing the preform, consisting of three layers; two outside layers consist of primary polymer, and the inside layer is the polymer received during the recycling. While modelling the material of each preform layer, a viscous-elastic model of the material is used; this model allows identifying the deflected mode within each layer and between the layers, taking into account the change of polymer viscosity in the non-uniform cooling conditions. The dependencies of deformation rate intensity on blowing pressure for each of three layers of a multilayer product are calculated.

1. Introduction
The growing need for polymer products and package with a specified regulated properties complex requires higher equipment productivity with technological advancement of manufacturing polymer products. The main way of getting polymer products with specified properties is the multilayer polymer materials design. Besides, the usage of multilayer extends the opportunities of polymer products utilization, in case when the inside layer in the multilayer system is formed out of polymer wastes; thus, the ecological problem of recycling is solved [1-3].

Due to the range of valuable service properties polymer materials are widely used in technology and everyday life. However, along with the valuable properties, these synthetic products also have some drawbacks. The main drawback is that, as opposed to many natural materials, polymers, having fulfilled their functions, are not destroyed quickly enough under the influence of aggressive environmental factors such as light, heat, atmosphere gases, microorganisms; but they continue their existence in the form of long-lived wastes, in some cases causing the irreplaceable damage to the wildlife [2-5].

In the conditions of polymer feed stock rise in cost plastic wastes are becoming powerful raw materials and energetic source. The usage of polymer wastes allows saving significantly primarily raw materials (first of all, oil) and electric power. The following stages of polymer circulation in the social consumption are viewed from this point: synthesis → processing → modification → use → collection.
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and separation of wastes → secondary recycling → re-employment → collection and separation of wastes → and etc., until the final waste utilization [6-7].

Processing of the secondary polymer materials comprises three main groups of processes: preparatory, shape-generating, and auxiliary. Preparatory processes unite the operations of wastes conversion into raw materials (powder, granules), suitable for further processing into products. Shape-generating processes comprise plastic working operations for alteration of polymer raw materials into products (molding, extrusion, press molding, blowing molding, pneumo- and vacuum molding, calendering). Auxiliary processes unite finishing and development operations, for example: giving an attractive appearance to the readymade products, making permanent connections out of separate product elements, and etc. [8-10].

At present coextrusion with further blowing is one of the most effective molding methods of container molding with the application of the range of related technologies. The basis of the method comprises continuous polymer plasticization in several extruders with further getting of a multilayer preform in the form of a pipe and a cyclic molding in the molding tool by means of compressed air injection into the preform. The blowing goes immediately after the required length preform input into the molding tool in the course of continuous coextrusion process without extruders stopping [11-13].

2. The problem statement
The known ways of getting multilayer polymer systems are based on the usage of their melts plastic working [14-15]. For this purpose special equipment is developed; at present this equipment does not always ensure the required productivity and product quality. Hence it is necessary do design the deflected mode model of a multilayer polymer preform in the process of plastic working.

3. Theory
In connection with large multilayer polymer volumetric product range and calculation universality we introduce an assumption of a spherical bottom form of the product. First we will consider the technological process characterization of the impulse blowing of the polymer container multilayer bottom.

One of the most important characterization is blowing pressure the quantity of which has to be sufficient for the multilayer structure compaction and for ensuring solid adhesive connection [16]. Besides, the air pressure maintains the required positional relationship of the preform layers in the blowing mold cavity for the fast product cooling; this increases the product quality and the extruder efficiency [17].

The mechanical properties of the multilayer envelope material are characterized by the tension-deflection diagram with a linear hardening in the plastic domain. The adhesion between multilayer envelope layers appears if the deformation of every next layer is higher than of the preceding one:

$$\varepsilon_i^+ > \varepsilon_i^-.$$  \hspace{1cm} (1)

The calculation of the multilayer preform adhesion is done for different loading conditions:
a) the load is applied to all the points of the inside surface;
b) the successive loading of the inside surface points of the multilayer preform by the pressure progressive wave (figure 1).
The preform consists of three layers. The material of each layer is polyethylene PE -15803-020. The layers are of the same thickness $\delta = 1 \text{mm}$. The outer diameter of the sphere is 80 mm.

The work [18] shows that if the load is applied to all the points of the inside surface simultaneously, then the condition (1) is not satisfied; thus, the use of central spherical blowing for multilayer wall compaction is impossible.

In connection with this the research of the process of blowing multilayer preform in the mold is carried out; the research results show that the increase of intensity deformations in the outside layer in comparison with the inside layer during their joint deformation happens due to the bend of the preform layers.

In case of the successive loading of the inside envelope surface by the pressure progressive wave, the condition (1) is satisfied at the moment of the outside envelope layer contact with the form mirror. Therefore, during the unloading we will get the guaranteed tension.

Good adhesion is achieved if every further gap, starting with the mold, is twice or more times less than of the previous one. Along with this, the more the gap is, the higher the required blowing pressure is.

In the condition of minimum blowing pressure the best results are obtained when there are gaps between the layers and those gaps are less than the gap between the outside envelope and the mold [19].

That is why the adhesion between the layers has to be provided in two stages. At the first stage it is necessary to make a preliminary adhesive connection of the multilayer preform in the coextrusion head (primary molding); at the second stage it is necessary to load the multilayer envelope with the air pressure during the blowing in the mold (secondary molding).

Polymer coextrusion theory and practice show that the primary molding process, stabilizing the preform sizes, is provided with certain process-dependent and constructive parameters of the coextrusion head. During the secondary pulse processing the preform molding is provided by the blowing pressure, which is created by the compressed air going through the nipple or the needle inside the blown mold.

However, in the range of manufacturing schemes of secondary molding it is possible to implement a glancing collision of the multilayer structure with the mold or with the outside layer by the means of special profiling of the surface composite layer [20]. In this case it is necessary to provide a constant given angle of collision in steady-state conditions.

In general terms the solution to this task is formulated as follows: the given mold surface is described by the equation of the type $F(x_1, x_2, x_3)$. It is required to determine the preform mold.
4. Results and Discussions

For guaranteeing the high quality of the secondary polymer product it is necessary to meet the requirements (1) by means of choosing optimum process-dependent parameters at the blowing multilayer preform stage. That is why it is necessary to research the deflected mode (DM) in the process of preform blowing; the preform consists of three layers, the two outside layers consist of the primary polymer, and the inside one consists of the polymer received during the recycling. The possible schemes of multilayer structure molding and adhesion are presented in figure 2.
While doing the task, the modelling of the given manufacturing operation with the application of finite difference method (FDM) in the frames of the “preform-mold” system is done. The design model is presented in figure 3 a, the final blowing stage is presented in figure 3 b.

In this research while modelling the material of each preform layer a viscous-plastic material model is used; this model allows determining DM inside each layer and between the layers, taking into consideration the polymer viscosity change in the conditions of non-uniform cooling.

As a result of modelling, the highest tangential stresses dependency on the blowing pressure is obtained (figure 4).
Figure 4. The highest tangential stresses dependency on the blowing pressure:
1 – tangential stresses intensity; 2 – critical stress shift

The critical value of stress shift at the blowing of multilayer polymer preform is 100 kPa: at the excess of the preform tangential stresses intensity during the interaction with the blown mold the final product quality worsens considerably. Thus, according to the modelling results it is reasonable to use the blowing pressure range up to 0.5 MPa.

Figure 5 presents the distribution of the highest deformations intensity by the layers of a multilayer pipe polymer preform.

Figure 5. Distribution of the highest deformations intensity by the layers:
1 – inside layer; 2 – middle layer; 3 – outside layer

For even microlayers overlapping the deformation by the layers, while blowing the pipe preform, has to be maximum close on each layer. Thus, the optimum blowing pressure value is 0.5 MPa.

Figure 6 presents the results of modelling the deformation rate intensities on the blowing pressure by the layers of a multilayer pipe polymer preform.
Figure 6. The dependence of the deformation rate intensities on the blowing pressure:
1 – inside layer; 2 – middle layer; 3 – outside layer

For even layers overlapping, while blowing the pipe preform, their deformation rate has to be maximum close. Thus, by analogy with the previous dependency the optimum blowing pressure value is 0.5 MPa.

5. Conclusions
On the basis of multilayer envelope dynamic equations, which consider kinematic, dynamic and energy conditions on the surfaces of layer contacts, we identified the conditions which provide plastic deformation of polymer material adjoining layers and good adhesion between the layers of the primary and secondary polymers.

As a result of deflection mode modelling, the optimum blowing pressure value is 0.5 MPa, which provides even layers overlapping.

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