EXPERIMENTAL RESEARCH OF THE INFLUENCE OF SELECTED SBM PROCESS PARAMETERS ON THE PET CONTAINERS PROPERTIES AND ANALYSIS OF THE PET MULTI-PHASE MICROSTRUCTURE

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1. Stretch Blow Molding process (SBM process)

The production of containers for beverages made of PET material with viscosity IV = 0.76 - 0.85 dl/g takes place in a so-called "Two-stage manufacturing process" (ISBM process). In the first step it is made a semi-finished product by injection molding, the so-called "preform", and in the second step by the blow molding with the simultaneous stretching (stretch blow molding process - SBM process) this preform is being shaped into the finished product (defined by the shape of the cooled blow mold). A detailed description of the ISBM process was presented in other author's works [1,2].

The properties of the bottle manufactured in the SBM process are influenced by thermodynamic, mechanical and physico-chemical phenomena. Thermodynamic effects are associated with heating the preform, rapid cooling of the blown bottle by the walls of the blow mold (and in part by a stretching rod), and with the heat exchange between the blown preform and the blow air. Mechanical phenomena and fluid mechanics are related to the speed of the stretching rod, the air pressure of the pre-blow and main blow, the flow rate of the air through the blow valves and exhaust flow rate of air trapped between the blown preform and the wall of the blow mold through the channels drilled in the blow mold. Physicochemical phenomena are associated with phase changes occurring in the PET material during the SBM process. All these phenomena affect in a coupled and nonlinear manner affecting the properties of the bottles PET material.

2. PET multi-phase microstructure model

It is very difficult to describe the whole issue of the SBM process in the terms of describing the influence of SBM process parameters on the microstructural properties of the PET material. The problem is that the amorphous phase itself occurs in 5 forms: the mobile unoriented amorphous phase, the rigid unoriented amorphous phase, the oriented amorphous phase, and this occurs in form of the nematic, smectic type C and smectic type A [3]. The crystalline phase occurs in two forms: a temperature-induced crystalline phase, and a strain induced one.

Simplifying the problem of behavior of PET in the SBM process, in the preform individual polymer chains usually form unordered amorphous entanglement, where individual chains influence the behavior of the material over a large area. This effect is due to the fact that individual macromolecules form entanglement with other macromolecules. Moreover, if there is a stress field (e.g. by deformation or elevation of temperature) the entanglement of macromolecules may disappear. These entanglements are randomly arranged, and from a macroscopic point of view, a polymeric material containing only an amorphous unoriented phase behaves like an isotropic material. The behavior of the chains relative to each other is determined by the stress field, which depends on the external extortion (deformation, temperature), but also on the interaction between the individual chains. In the SBM process, the deformation is so large that the polymer chains are orientated towards the deformation causing a change in the material structure, and consequently its mechanical properties - the unoriented amorphous phase is transformed locally into an oriented amorphous phase. As a consequence, the material exhibits anisotropy characteristics. Moreover, the oriented amorphous phase can form nucleation of crystallization, which can lead to the transformation of the oriented amorphous structure into the crystalline phase - this is called strain induced crystallization.

In addition, individual areas can be subjected to several microstructural changes. The oriented amorphous region can be transformed into a crystalline region (if a stable nucleation of crystallization is formed) or it can be transformed into an initial form (amorphous unoriented) and later can be transformed into an oriented amorphous phase (and possibly further to the crystalline phase). In turn, the formed crystalline phase may break into a rigid amorphous unoriented phase. It differs in properties from the mobile unoriented amorphous phase, because it is predominantly composed of trans conformation whereas in the mobile amorphous phase, the probability of trans and gauche conformation is comparable (the crystalline phase contains only trans-conformations). In theory, it is assumed that at temperatures lower than the glass transition temperature, it is possible to convert between the oriented amorphous phase and the unoriented amorphous phase, but it is impossible to create a crystalline phase.

3. Experimental research

The purpose of the research results described in the paper is to determine, by means of ANOVA, the existence of qualitative and quantitative influence of selected SBM process parameters (factors) on the macroscopic characteristics of bottles, i.e. the thickness profile and pressure resistance of bottles. Main effects and cross-effects were analyzed. In addition, the results of macroscopic features of bottles were explained on the basis of multi-phase polymer structure theory, and the given interpretation was supported by literature data.

In terms of the influence on the thickness profile were examined the speed of the stretching rod (1), pre-blow air pressure (2) and WSR parameter (3). In terms of influence on pressure resistance were examined the speed of the stretching rod (1), pre-blow air pressure (2), WSR parameter (3) and preform temperature (4). The effect of factors 1, 2 and 3 on the thickness profile and pressure resistance were tested on the basis of a complete divalent three-factor plan (three-factor MANOVA). On the other hand, the influence of preform temperature on pressure resistance was tested on the basis of a divalent one-factor plan. The stretching rod speed varied from 0.72 m/s to 1.2 m/s, pre-blow pressure from 6 bar to 9 bar, and WSR parameter from 120 mm to 160 mm. The influence of preform heating by the heating furnaces on the preform temperature was measured by two pyrometers just before preform was being put into the blow molds. The average temperature of the preforms was 123°C for lower heating power and 132°C for higher heating powers.

The presented analysis showed that the changes in macroscopic features can be explained on the basis of the currently functioning theory of multi-phase PET material microstructure.

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