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Multiaspect analyzes of blow moulding process

K. Szczepański*, D. Kwiatkowski, J. Koszkul
Department of Polymers Processing and Production Management,
Technical University of Częstochowa, Al. Armii Krajowej 19C, 42-200 Częstochowa, Poland
* Corresponding author: E-mail address: szczepanski@kpts.pcz.czest.pl

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Materials

ABSTRACT

Purpose: The main purpose of the performed investigations was a multi-aspect analyzes of the blow moulding process in a mould which takes two-stage nature of the process and the occurrence of uncontrolled phenomena which influence the shape, size and quality of the products into consideration.
Design/methodology/approach: The value for the Barus number for different dimensions of the nozzle gap and the distribution of the temperature field during blow moulding process have been determined; the product thickness profile has been defined; phenomena which occur during blowing stage have been registered. The investigations have been performed by means of the blow moulding machine of UFP-05 type by IPTS – Metalchem Toruń using the designed and prepared blow mould with the sight-glass made of polycarbonate.
Findings: The performed investigations enabled the insight study of uncontrolled phenomena which occur during each individual stage of the process and they showed the dependencies between these phenomena and the process parameters. Moreover, the detailed analyses enabled to determine the influence of these parameters on the physical features and dimensions of the finished goods.
Research limitations/implications: The continuation of the investigations with use of extended blow mould design equipped in polycarbonate sight-glass which enabled the determination of the influence of the structure and mould cavity dimensions on the finished product wall thickness seems to be justified. It would be also useful to design the station for the precise non-touch measurements of Barus effect which enabled, except the measurements of the external diameter, the measurements of the finished product wall thickness.
Originality/value: The complex analysis of the blow moulding process was possible thanks to innovative and original approach to the experimental tests which enables e.g. the optical registration of the phenomena which occur during blow moulding process.
Keywords: Engineering polymers; Working properties of materials and products; Plastic forming; Blow moulding; Product quality

1. Introduction

Blow moulding is a process of thermoplastics processing which consists in continuous extrusion moulding of the plasticized parison which after leaving the angular head is then blown out under the influence of the compressed air and reflects the shape of blow mould cavity [1, 2]. During the blow moulding process the finished products are manufactured in a cyclic way, while continuous extrusion of the semi-finished product in the form of plasticized parison.

A characteristic feature of the process is its two-stage nature. First stage means an extrusion which is performed continuously, which results in obtaining the semi-finished product in the form of plasticized parison. The second stage is a blowing process which is performed in a cyclic way and results in obtaining finished product [3, 4]. The chart below shows the division of the blow moulding into the extrusion and blowing stage; it can be further divided into the phenomena which occur during its individual stages and phases, which is shown in the Fig. 1.

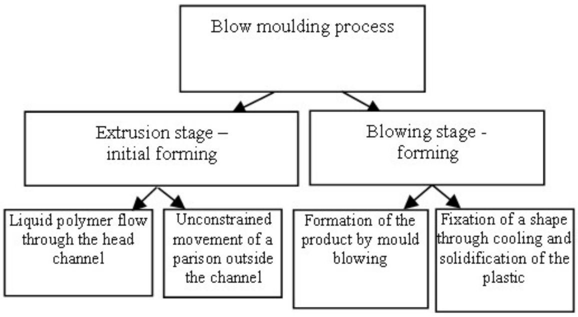

Fig. 1. Schematic division of the blow moulding process

Additional occurrence of the uncontrolled phenomena (e.g. Barus effect or Weissenberg effect) which depend on the viscoelastic properties of the plastic and the parameters of the process have a significant influence on the properties and the quality of the products. Therefore a significant role has the determination of the behaviour of the plastic during the processing, through the multi-aspect experimental analysis which leads to the determination of the influence of the mentioned phenomena on the quality of the obtained products [5, 6, 7].

2. Methodology

In order to perform multi-aspect analysis of the process the following experimental investigations have been performed:

- experimental investigations of the extrusion stage which lead to the determination of the Barus effect for different values of the extrusion nozzle gap (1.1; 1.5; 1.9; 2.3; 2.6mm),
- experimental investigations of the extrusion stage, which included the registration of the non-isothermal phenomena by means of thermovision camera,
- experimental investigations which led to the determination of the thickness profiles for the products obtained from the semi-finished product with different initial thickness,
- experimental investigation of the blow moulding stage, which led to the registration, by means of the digital video camera, of the phenomena occurring during the process,

The investigations have been performed by means of the extruder machine W25 with the UFP-05 device for formation of the containers using blowing method manufactured by IPTS – Metalchem Toruń, which is in stock of the Institute of Polymer Processing and Production Managemen, Czestochowa Technical University. The investigations have been performed for the products in shape of the bottle and the rectangular prism made of low density polyethylene PE-LD Malen-E.

2.1. Determination of the Barus number

In order to determine the values of the Barus effect the blow moulding tests have been performed for different dimensions of the extrusion nozzle gap (1.1; 1.5; 1.9; 2.3; 2.6mm), while the photographs were taken by means of the digital camera. The photos were then subjected to the computer analysis which consisted in the comparative measurement of the longest diameter of the parison. The comparative measurement means comparison of the determined value of the external size of a parison with the auxiliary scale graduation and reading the obtained value on this scale, multiplying this value by correction coefficient determined on the basis of the experimental tests, equal 1.22. This enables to calculate the outer diameter of parison.

Application of the correction coefficient is caused by the existence of the optical error which appears as a result of different distances from the digital camera to the auxiliary scale and from the camera to the extrusion head axis (the difference amounted to 60mm). The parison diameter $\mathbf{d_s}$ has been calculated from the equation:

$$d_s = d_O \cdot w_P \tag{1}$$

with: d_O – the diameter read from the auxiliary scale, w_P – correction coefficient of 1.22.

2.2. Measurements of the temperature distribution on the parison surface

One of the applicable methods of the temperature distribution measurements on the parison surface during blow moulding process is a thermovision method. Each objects and bodies whose temperature is higher than the absolute zero (273,15°C) emits the infrared radiation. The higher the temperature of the investigated object the higher intensity of this emission. The phenomenon is used in thermovision. The measurement by the thermovision method consists in the analysis of the pictures from special infrared radiation detector in-built in the thermovision camera [8].

During the investigation the ThermaCam PM 590 thermovision camera produced by American company FLIR has been used. The purpose of the tests was not to determine the temperature of the tested object but only the distribution of the temperature on its surface. The measurements were taken with the following conditions:

- The temperature registered by last thermo-couple placed in the extrusion head - 150°C,
- ambient temperature - 20°C,
- mean extrusion speed $\overline{v}_w$ - 9.17×10^{-3} [m/s],
- value of the extrusion nozzle channel gap – 2.6 [mm].

2.3. Registration of the phenomena which occur during the blowing stage

The registration of the phenomena which occur during the blowing process were performed by means of a video camera. This was possible thanks to the application of the specially designed blow mould whose one of the walls had in-built sightglass made of polycarbonate. The blowing air is led by the air nozzle with the dimension of 1.5mm located in the middle of the lower wall of the rectangular prism.

3. Investigation results

3.1. Barus effect

The outer diameter of the parison has been determined for different values of the extrusion nozzle gap and the exemplary results and values of the Barus number are shown in the Fig. 2

The experimental investigations proved that decrease in the extrusion nozzle gap caused increase in the value of Barus number within the range of 105÷112%. The decrease in gap dimensions, while keeping the continuous value of volume flow rate, caused the increase in shear rate during the flow of polymer through extrusion head channels and, consequently, the change in value of cross viscosity and, as a result the increase in the value of Barus number.

It should be mentioned that in this case only the outer diameters of the parison have been determined. On the other hand, when the forming tool for the parison is an annular jet nozzle, not only the increase in the outer polymer jet diameter occurs as a result of Barus effect but also the decrease in the inner diameter of the parison [9]. The experimental determination of the inner diameter is connected with the need to build the measurement station equipped in several ultrasound sensors which enabled non-touch determination and measurement of the parison thickness during the blow moulding process.

3.2. Temperature distribution on the parison surface

The photographs obtained from the thermovision camera were then processed by the special-purpose software. Series 3 of the photographs presents individual changes in the parison temperature which occur during the extrusion process. On the photos shown in the Fig. 3 it is visible that the temperature distribution on the parison surface is varied and, depending on the distance from the extrusion head it takes the value of from 160°C to 140°C.

The reason for this diversity of the temperature field on the parison is the convection-like heat transfer which leads to gradual cooling. Moreover, the thermovision results of the investigations proved the existence on unsymmetrical distribution of the temperature on the parison. The probable reasons for such results are different convection conditions or diversity of the parison thickness caused by the tool tolerance. The latter reason is more probable since insignificant difference in wall thickness connected with the tool tolerance is the reason for lower thermal capacity and what follows, its faster cooling.

3.3. Registration of the phenomenon which occurs during blowing process

Next stage of the investigations was recording, by means of the digital camera, the course of the blowing process, which was shown in the Fig. 4. Since the basic blowing process takes merely 0.4sec, it was necessary to apply the computer techniques which enabled frame-by-frame analysis of the registered phenomenon every 0.04s. While analysis individual phases of the blowing stage it can be observed that clamping the blow mould caused the flattening the parison. After switching on the blow pressure the invariable extension of the parison can be observed, and, consequently, equal change in wall thickness, until the occurrence of the contact of parison with the mould, after which the wall thickness does not change. However, the areas where the contact did not occur (Fig. 4) are more intensively extended until the moment of full reflection of the mould cavity shape. The most intensive thinnessness of the wall occurred in the corners of the product, i.e. the areas of the most intensive extension and the places of the latest contact of the parison with the form. The results were confirmed by the results of the experimental investigations, which, similarly, showed significant change in product wall thickness for the same areas i.e. in rectangular prism corners.

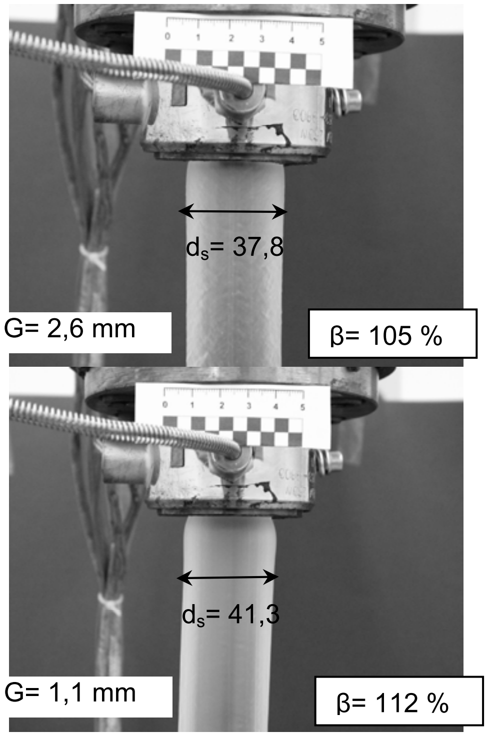

Fig. 2. Examples of the results for Barus number for individual values of the extrusion nozzle gap G [mm]; d_w – the diameter of the parison in place of the phenomenon of jet extension [mm], β – Barus number [%]

4. Conclusions

The obtained results enable to formulate the following conclusions:

1. The results of the experimental investigations of the extrusion stage on the influence of the extrusion nozzle gap dimensions on the Barus number prove that the decrease in extrusion nozzle gap dimensions, causing the increase in plastic share rate,

influence the increase in Barus number. Moreover, the increase in outer diameter of the parison caused by Barus effect has a local and transient nature with a tendency to fade away.

2. The thermovision investigations. In case of the parison the highest temperature was observed (150°C) at the area of the extrusion nozzle, which gradually decreases, due to the unsteady cooling, with the distance from the nozzle (140°C). Moreover, the results of the thermovision investigations proved unsymmetrical temperature distribution on the parison and the product. The probable reason for obtaining such results were different cooling conditions during unconstrained extrusion and shaping in blow mould and/or diversity of the parison thickness connected with the tool tolerance, i.e. extrusion nozzle tolerance.
3. The registration of the blowing stage by means of the digital video camera enabled direct observations of the phenomena which occur during the blow moulding process. The observation showed that the biggest thinnessness of the wall occurred in the corners of the product of "rectangular prism" shape and is caused by the most intensive extension of the parison in this area; it is also the place of the latest contact of the parison with the mould. The thickness of the wall is basically influenced by the shape and dimensions of the mould cavity, which is connected with the varied extension rate for the individual areas of the parison and varied time of contact of the parison with the mould. Since the geometrical shape of the mould cavity is limited by the demanded shape of a final product, the regulation of the wall thickness profile of the finished product is possible only by controlling the parameters of the extrusion stage which lead to obtaining the appropriate parison thickness profiles with consideration of the places where the most intensive extension during blowing will occur.

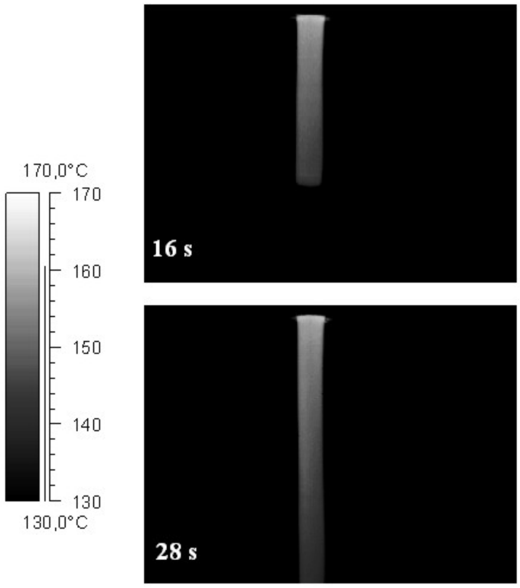

Fig. 3. Photographs which show the temperature distribution for the parison during the blow moulding process performed by means of infrared method with thermovision camera. The number in left down corner of each photo means the time which has passed since the beginning of the blow moulding process.

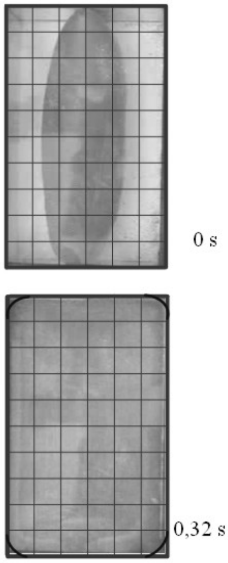

Fig. 4. Comparison of chosen results of experimental registration and simulation (product thickness distribution of „rectangular prism" type) for different blowing time.

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