Journal of Polish CIMAC
Gdansk University of Technology
The Faculty of Ocean Engineering and Ship Technology

ANSYS POLYFLOW SOFTWARE USE TO OPTIMIZE THE SHEET THICKNESS DISTRIBUTION IN THERMOFORMING PROCESS

Karol Pepliński, Arkadiusz Mozer

University of Technology and Life Sciences in Bydgoszcz
ul. Prof. S. Kaliskiego 7, 85-789 Bydgoszcz, Poland
tel.: +48 52 3408224, fax: +48 52 3408222
e-mail: karolpep@utp.edu.pl

Abstract

Thermoforming is a manufacturing process widely used to produce thin thermoplastic parts from small blister packs to display AAA size batteries to large skylights and aircraft interior panels. In this paper was presented numerical simulation of the inflation phase of a thermoforming process under which a thin polymer sheet is deformed into a mould under the action of applied pressure. Two cases of blowing sheet were considered. In the first, preapproved on the basis of a constant sheet temperature (T = 150°C) examined the distribution of the container wall thickness. There has been excessive thinning (about 0,2mm) in the cup corners after forming. Also simulation it was made for other constant temperature (160, 170, 180, 190 and 200°C). On this basis, was made optimization of the sheet profile temperature (in range 150÷200°C) to remove excessive thinning. Noted was a significant effect of the initial sheet temperature distribution on the final wall thickness distribution in the considered container. The Ansys Polyflow procedure of optimizing the sheet temperature distribution allowed eliminating excessive thinning in the considered cup walls corners.

Keywords: *thermoforming, Ansys Polyflow simulation, non-isothermal conditions, optimization sheet temperature*

1. Introduction

Thermoforming is a manufacturing process widely used to produce thin wall thermoplastic products. The temperature of a previously extruded thermoplastic sheet is raised far above the glass transition temperature and next deforms the material to the desired shape using a differential pressure and a male or female mould [3,11]. This process is used mostly for various packaging industries, such as food, because of various advantages like, ease of production, low cost, high speed and high performance [1,7]. The major raw materials used for thermoforming are high impact polystyrene ABS, PVC, polypropylene, HDPE, Polycarbonate etc. The choice of each material depends upon the end-use requirements and cost. The most common materials used for disposable wares are high impact polystyrene, PVC and polypropylene (considered in work) [2,8].

Nowadays the thermoplastic forming industry is mostly based on trial and error methods to design and develop new products. These procedures, however, result relatively time and money expensive [6,10]. Helpful solution is to use CAE software Ansys Polyflow. This software makes it possible to determine the behavior of the plastics during the process, identify areas where there may be the biggest product wall thinning, which reduce the mechanical properties of the product.

At the end of a thermoforming process, we can observe non-uniformities in the thickness distribution in some areas, the sheet can be too thick, while in other areas, it is too thin. Instead of increasing the initial thickness of the sheet in order to obtain a minimum thickness everywhere, it is possible to play with initial temperature distribution. Sheet temperature is one of the most critical elements of the thermoforming process. It is sheet temperature that dictates the process, the end result being not just a better product, but also decreased cycle time, less scrap and reduced energy and labor costs. We can increase the heat on a part of the initial sheet that eventually leads to an area with an excess of matter. This makes it possible to improve the thickness distribution in the final sheet product without increasing the mass of the sheet. Software Ansys Polyflow own ability to optimization initial temperature of the sheet.

The purpose of this paper is determined the impact temperature distribution along the sheet on the final cup thickness is taken into account. Simulations are carried out using Ansys-Polyflow 12.1 software [13].

In an earlier some author study [9] considered only a one constant temperature distribution sheet, and then optimized structure of sheet temperature distribution. Whereas, not studied the influence of different range of constant initial sheet temperatures on the final product thickness distribution of what this has been presented below.

2. Modeling and numerical algorithm

From a geometrical point of view, the thermoforming process involves a fluid region – the sheet, the thickness of which is two to three orders of magnitude lower than the other dimensions [13]. This specific geometric aspect ratio enables the use a membrane approach. This issue allows the study of complex situations at a moderate computational cost. The fluid sheet will be geometrically described by means of a membrane representing its mid-surface. Let h and v denote the sheet thickness and the mean velocity vector in the mid-surface of the membrane respectively. During sheet inflation, the sheet motion will be governed by the equations of mass and moinentum conservation combined to a constitutive relationship. In the membrane approach, the thickness h is considered as an unknown and obeys the following continuity equation [5,13]:

$$\frac{Dh}{Dt} + h\nabla \cdot v + 0\,. \tag{1}$$

In equation (1) expression D/Dt mean denotes the material derivative with respect to time t.

The momentum equation is a balance of several forces: contact forces at the mold surface, inflation pressure, fluid stresses, inertia. By simultaneously considering the moderate dimensions of the part presently investigated and the short time scales involved, gravity effects are negligible. The momentum equation is weighted by the thickness h and is given by [5,13]:

$$\nabla \cdot N + f_p = \rho h \frac{Dh}{Dt}\,. \tag{2}$$

In equation (2), ρ is the fluid density, f_p is a surface force which stands for the inflation pressure, while N is the tensor of contact forces per unit length. N is obtained by weighting in h the extra-stress tensor T built by using the assumption of stress free inner and outer surfaces of the membrane. For a Newtonian fluid, the extra-stress tensor T is given by [4,5]:

$$T = 2\eta D\,. \tag{3}$$

In equation (3) η is the fluid viscosity and D is the rate of deformation tensor.

The treatment of the sheet – cavity contact is an important ingredient in the simulation. In absence of contact, the location x of a fluid particle is controlled by kinematic equation [4]:

$$\frac{\partial x}{\partial t} = v \, . \tag{4}$$

When a fluid particle enters into contact with the mould, its relative motion with respect to the mould wall vanishes, and equation (4) is replaced by a velocity condition. This new condition is introduced by means of a penalty formulation [4,13]:

$$f = k(v - w) \, . \tag{5}$$

In equation (1) k is the penalty coefficient and w is the mould velocity.

During sheet inflation, w vanishes. Wall slipping at contact may also be taken into account [4,5].

The finite element method is used for solving the flow governing equations (1) and (2) with the kinematic equation (4). In the case displayed in Fig. 2, the mesh covering the sheet domain contains 40856 triangular surface elements. The time integration of equations (1), (2) and (4) is performed by means of a time-marching scheme.

3. Process description

The object considered in the Polyflow simulation is axially symmetric cub, whose shape and dimensions are illustrated below. Fig. 2 illustrated the initial configuration of sheet and mold cavity position adopted for the simulation run. Sheet and mold are located s = 10 mm to each other. Sheet dimensions are 120 x 120 mm and initial thickness is g = 1 mm. The material for the sheet is the PP, which have a temperature of T = 150 °C, viscosity μ = 8630 Pa•s and density ρ = 0.9 g/cm^3 and was used in thermoforming process in rang of temperature (150÷200)°C [12]. The run of the

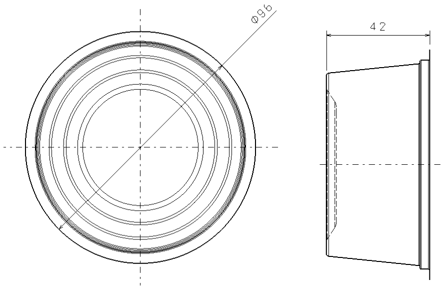

Fig. 1. Considered model [9]

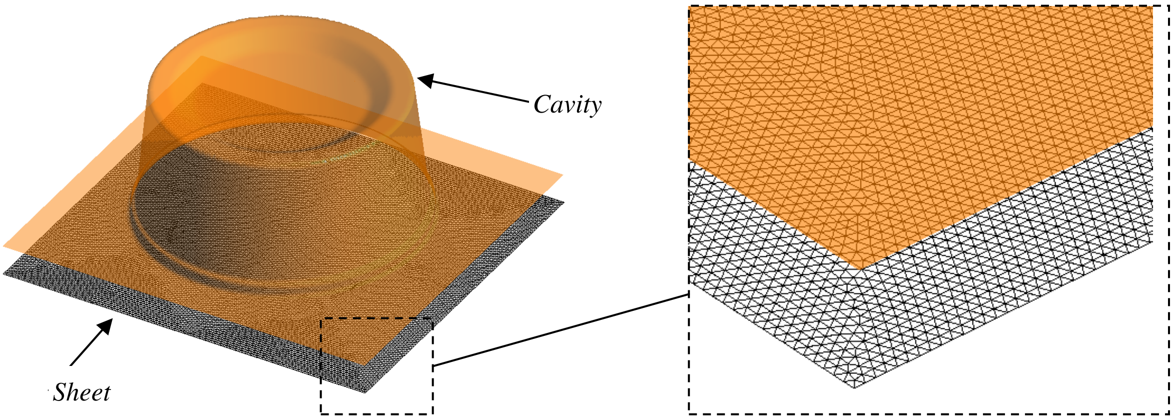

Fig. 2. Initial configuration of polymer sheet and mold cavity with sheet MES grid configuration

whole process starts with the closure of the mold. The mold is moving with a velocity v = 50 mm/s. Then blowing pressure is accompanied with a value of p = 0.5 MPa and running until the cup is blown. Total time blowing process simulation is 1 second. Seventh cases of blowing sheet were considered, six with uniform temperature across the sheet (150, 160, 170, 180, 190 and 200°C) and one with optimized temperature profile in range (150÷200)°C. An established criterion for a minimum wall thickness in the final product was 0,3 mm.

4. Simulation results and their analyses

Realized simulations generated series of results, which the selected part is presented below. Fig. 3 shows a comparison the distribution of thickness cup obtained from the sheet with constant and varied temperature distribution, along a given line of measurement. An established optimized criterion for a minimum wall thickness (0,3 mm) in the final product was achieved only for case 7, in which the temperature of sheet was optimized. Presented 1-6 simulations showed significant differences in the value of the cup wall thickness distribution compared to the case 7. Visible improvements of the wall and corner thickness distribution were observed in case 7. Graphical

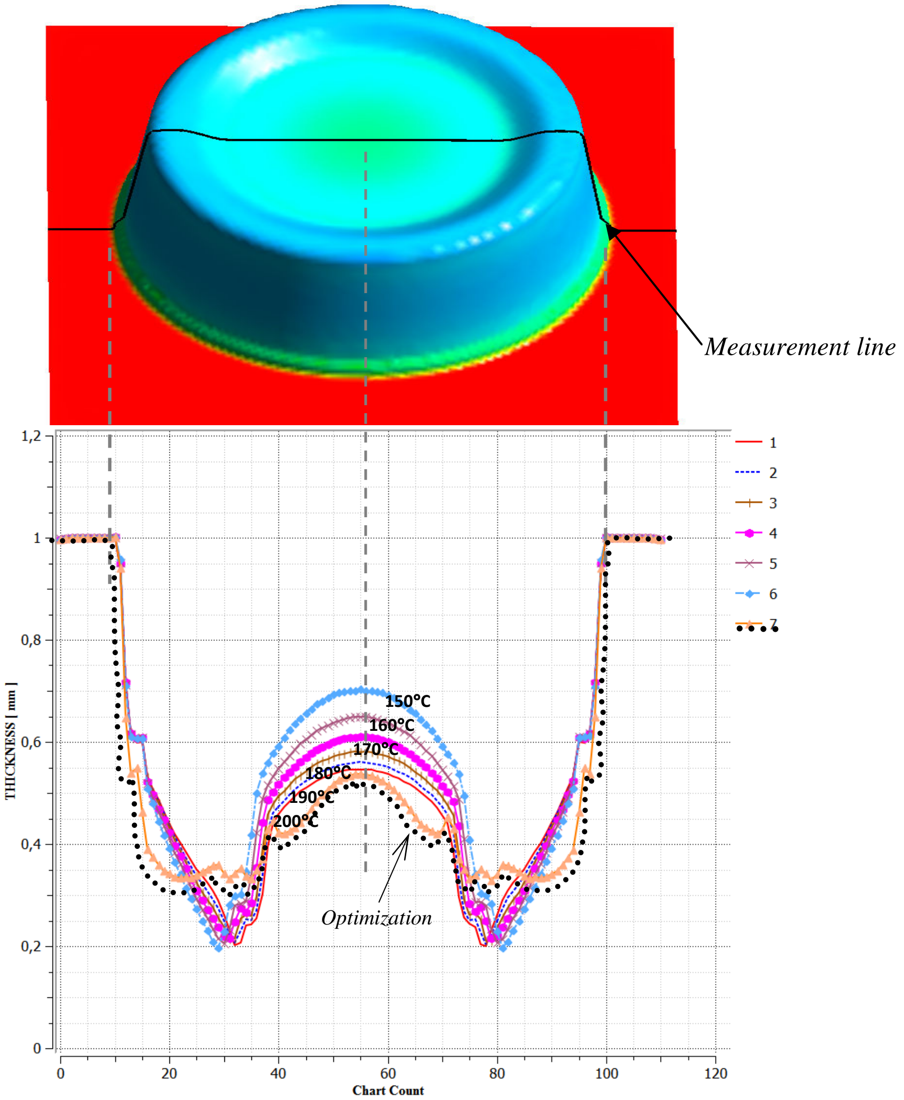

Fig. 3. Comparison part thickness distribution along the measurement line: 1 – sheet with temperature T= 150 °C, 2 – sheet with temperature T= 160 °C, 3 – sheet with temperature T= 170 °C, 4 – sheet with temperature T= 180 °C, 5 – sheet with temperature T= 190 °C, 6 – sheet with temperature T= 200 °C, 7 – sheet with optimized temperature T= (150÷200) °C

display before and after blowing container for two cases is shown in Fig. 4 and Fig. 5.

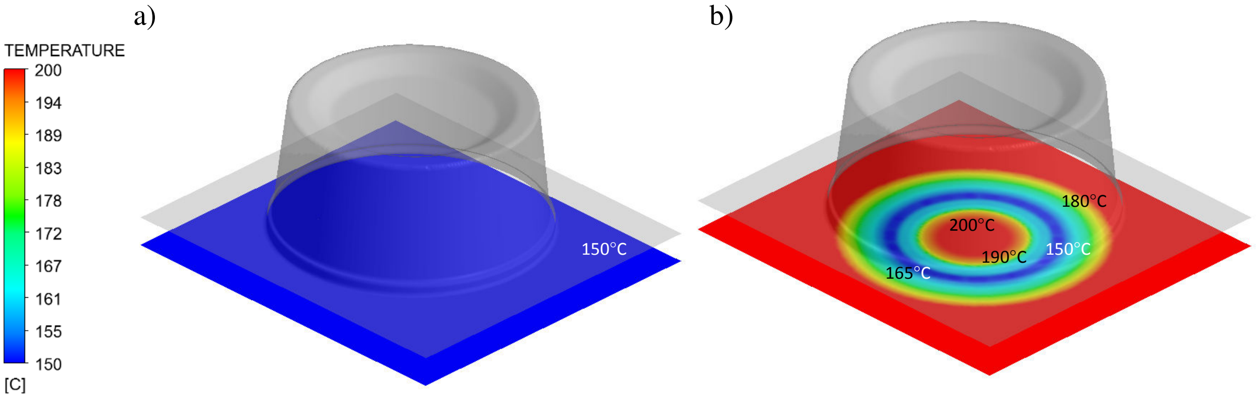

Fig.4. Schedule sheet temperature: a) constant $T= 150^o C$, b) optimized temperature profile $T= (150÷200)^oC$

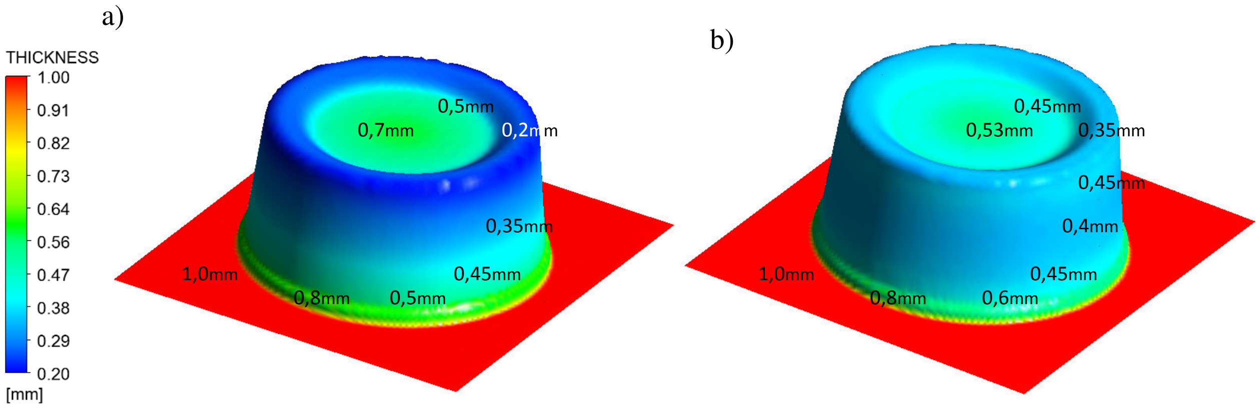

Fig.5. Final part thickness distribution for: a) constant temperature T= 150 °C, b) optimized temperature profile

5. Final consideration and summary

Assumption of equal heated sheet, caused the largest thinning container, and the most exposed to loss of continuity of the material were the corner of the packing (Fig. 4a, 5a). Completed subsequent simulations for different ranges of constant temperatures indicate a gradual bottom packaging thinning with increasing initial temperature of the sheet.

However a significant influence of the sheet temperature on the corner thickness isn't noticed. However, next three carried out optimized simulations with modified and diversified field temperatures while heating the sheet, considerably reduce differences in wall thickness distribution.

They achieved good results for the variant described on fig. 4b, 5b, for which achieved better wall thickness distribution with smaller thickness differences. The best results were achieved in corners where the value of the thickness is averaging 0.35 mm (and was below 0.2 mm). On the circumference of the package was improved wall thickness distribution in average range 0.4÷0.6 mm (was 0.25÷0.5mm). It provides the greater structural stiffness for the package while using.

Software Ansys Polyflow, enables to carry numerical experiment in the range of phenomena modeling during the thermoforming process. By steering specific sections of the immersion heaters it is possible to get the more profitable wall thickness distribution of formed elements. Especially in the case of complex geometry we have new opportunities of applying the technology of the vacuum forming. Numerical analyses are reducing the financial outlays and are shortening the time of starting production of new thin-walled thermoforming products.

Applying the Ansys Polyflow program can support technical production steps like optimizing the process in the range of wall thickness distribution what in the end the field of the tolerance is narrower and increasing product quality.

References

[1] Berdyshev, B., Hosseini, H., Modeling of deformation processes in vacuum thermoforming of a pre-stretched sheet, Polymer-Plastics Technology and Engineering, 45, pp. 1357–1362, 2006.

[2] Bourgin, P., Cormeau, I., *A first step towards the modeling of the thermoforming of plastic sheets*, Journal of materials processing technology, 54, pp. 1–11. 1995.

[3] Carlone, P., James, L., *Finite element analysis of the thermoforming manufacturing process using the hyperelastic Mooney-Rivlin model*, Springer-Verlag Berlin Heidelberg, pp. 794–803, 2006.

[4] Debbaut, B., *Prediction of extensions in 3-D blow moulding simulation*, Journal of Reinforced Plastics and Composites, 16, pp. 1255–1262, 1997.

[5] Debbaut, B., Homerin, O., *A comparison between experiments and predictions for the blow molding of an industrial part*, Polymer Engineering and Science, 39, pp. 1812–1822, 1999.

[6] Dong, Y., Lin, R. J., *Finite element simulation on thermoforming acrylic sheets using dynamic explicit method*, *Polymers & Polymer Composites,* 14, pp. 307–328, 2005.

[7] Klein, P., *Fundamentals of Plastics Thermoforming*, Morgan & Claypool Publishers, Ohio University, 2009.

[8] Piecyk, L., *Termoformowanie wyrobów wielkogabarytowych*, Laboratorium, 7, pp. 27–31, 2006.

[9] Sykutera D., Pepliński K.: *Zastosowanie oprogramowania Ansys-Polyflow do wspomagania wytwarzania opakowań formowanych próżniowo*. Inżynieria i Aparatura Chemiczna 1/2011.

[10] Warby, M. K., Whiteman, J. R., *Finite element simulation of thermoforming processes for polymer sheets*, Mathematics and Computers in Simulation, 61, pp. 209–218, 2003.

[11] Wiesche, S., *Industrial thermoforming simulation of automotive fuel tanks*, Applied Thermal Engineering. 24, pp. 2391–2409, 2004.

[12] Żenkiewicz, M., Szach, A., *Wybrane problemy termoformowania materiałów polimerowych,* Polimery, 55, pp. 337–350, 2010.

[13] Ansys Polyflow User's Guide, Ansys Inc., 2010.