Simulation on Effect of Preform Diameter in Injection Stretch Blow Molding

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Abstract. Polyethylene terephthalate (PET) is the most common material of resin for manufacturing plastic bottle by injection stretch blow molding due to its excellent properties. As various issues of health and environmental hazards due to the PET use have risen, PET bottle manufacture may be improved by minimizing the wall thickness to reduce the PET use. One of the critical qualifications of the manufacturing process which lead to the wall thickness distribution is the initial preform diameter. In this project, we used the ANSYS Polyflow with aim to evaluate the wall thickness distribution of PET bottle for different diameter of initial preform. As a result, only 4 mm preform diameter presented wall thickness below than 1 mm. On the other hand, at least 6 mm preform diameter can permit the wall thickness 1.3 mm i.e. at the shoulder area.

1. Introduction

Polyethylene terephthalate (PET) is among the common thermoplastic polymer resins that widely used in household, medical, food and beverages. The food and beverages industry was the greatest volume consumptions of plastic packaging in statistical report 2014 [1]. The global PET resin demand has been rising continuously over the years and is predicted to grow at a rate of 7.3% annually in 5 years starting from 2014 [2]. The extraordinary mechanical strength and toughness with the ease of processing have prompting the production of PET packaging products. However, as the demand of PET plastic increases significantly among the years, various issues have cropped related to health and environmental hazards [3].

Many approaches have been carried out to minimize those impacts. One of them is to reduce the materials used during the processing stage of PET bottle [4]. By practicing a sustainable design, the bottle manufacture may be improved by minimizing the thickness to reduce the PET use. One of the critical design qualifications of PET bottle which lead to its thickness distribution is the initial preform diameter. The initial preform diameter are extremely important to produce the optimal bottle mass and uniform final wall thickness distribution [5, 6]. Since reports of the wall thickness of PET bottle is still scarce, this project intends to evaluate the wall thickness distribution of PET bottle for different diameter of initial preform, with aim to obtain the potential thinnest wall of the PET bottle.

In order to study the PET bottle manufacturing process, Finite Element Method (FEM) has been widely used to replace the trials through repeating experiments, which can effectively save time and materials consumption. Schmidt et al. [7] through their viscoelastic constitutive equations have successfully estimated the contact kinetic, thickness and stress distribution. Code ABAQUS® has been
utilized by Chung [8] to optimize the process of stretch blow-molding for a PET bottle. He found that the sliding at neck area of the bottle made the more material flows towards the side wall and thus causing a thicker side wall by the end. However, the process temperature is assumed to be constant along the process. The ABAQUS model has neglected the effects of elasto-visco-plasticity and thermal behaviours of the PET material. The same approach were also been conducted by Bordival et al. [9] through their works to predict accurately the blow molding kinematics. They have successfully maintained the modelling of fluid-structure interaction presented between the preform and its utilized air flow.

BlowView Software has been proposed by Daver and Demirel [10] in predicting the way of blow molded preform in order to solve the non-isothermal solid mechanics equations of blow molding process. It comprised the thermo-mechanical material models in terms of viscoelasticity and visco-hyper-elasticity for PET and encountered the strain-rate and temperature effects which reverts the real performance of PET. Furthermore, they have used ANSYS Polyflow simulation to address the maximum top load and burst strength that could be affordable by the bottle. Other works that used ANSYS Polyflow were also done by Gupta et al. [11] to solve the problem dealing with the time and stage of PET resin fill-in the cavity of mold. The volumetric mechanical computation allows prediction of wall thickness distribution, force distribution and contact kinetic distribution.

In this project, we used the ANSYS Polyflow due to its great library of finite elements and material models as well as the application of automatic remeshing which is a major contribution to succeed a simulation process.

2. Methodology

In order to analyze the thickness of the bottle formed, Finite Element Analysis (FEA) was performed using ANSYS Polyflow and the data generated was quantified using Simple Digitizer. The method to conduct the ANSYS Polyflow simulation for identifying the thickness, stress and velocities distribution will be explained in detail in the following subsections.

2.1. Simulation procedure

2.1.1. Geometry
The preform and bottle mold were designed as 2D drawing using ANSYS Design Modeler. Because of the complexity of modelling operation in Polyflow, assumptions for procedure were made in general terms. The bottle mold was 350 mm in height (y-direction) with a width of 96 mm (x-direction).

2.1.2. Meshing
In this project, mapped face shell elements with sizing of 0.0001 m are used. The boundaries were set as shown in figure 1.
2.1.3. Setup

2D axis-symmetry time dependent FEM is defined in Polydata. All the parameters and mathematical expressions were assigned to be used at the setup stage. The sub-sections include models, material data, boundary conditions, remeshing, numerical parameters, outputs and thickness postprocessor.

Table 1. Material properties.

| Property            | Value       |
|---------------------|-------------|
| Shear rate dependent| 100 000 Pa.s|
| Density             | 1 g/cm³     |
| Gravity             | -981 g/cm³  |

Table 2. Numerical parameters.

| Numerical Parameters | Data       |
|----------------------|------------|
| Upper time limit      | 1.0        |
| Initial value of time-step | 1.0e-03 |
| Minimum value of time-step | 1.0e-07 |
| Maximum value of time-step | 1.0e-03 |
| Tolerance             | 1.0e-02    |
| Maximum number of successful steps | 200 |
| Implicit Euler methods| Enable    |

Table 1 and table 2 show the material properties and numerical parameters, respectively. Only some material properties were available for the sub-task in Polydata including density, viscosity, inertia term, and gravity. For those irrelevant properties in this sub-task, they will be grayed out straight away when accessing Polydata. A simplified behavior was assumed in this project on account of the accurate characterization for all mechanical behaviors for PET are very complex. Then, boundary conditions were set up by inputting slip coefficient, penalty coefficient as 1.0e+09, normal force as -2e06 (negative indicates the direction of fluid towards mold). Numerical parameters in table 2 was then inputted.

2.1.4. Solution and result

Contours of time steps were then shown graphically to present the relationship between parameters with their dependent variables.

2.2. Data quantification

Simple Digitizer software was used to quantify the data of images collected from the result generated using ANSYS Polyflow. Multiple points were ticked at outer-line and inner-line of bottle in the generated images to produce x-coordinates and y-coordinates values as the measurement position. The difference between outer-line and inner-line were then calculated to determine the wall thickness.

3. Results and discussion

3.1. Wall thickness distribution

Figure 2 shows the thickness distribution at final time-step. The results of wall thickness fluctuation along the measurement position marked using Simple Digitizer software is shown in figure 3.

![Figure 2](image_url)
Figure 3. Wall thickness fluctuation at different preform diameter.

As the diameter of the preform increases, the overall thickness for the final bottle formed were found to increase. The wall thickness for all preform diameters were seen the thickest at the finish then followed by the base of bottle. It can be observed clearly that the thickness at the body (middle lower part) is the thinnest. For 4 mm preform diameter, there were some parts formed almost cannot be clearly seen especially at the bottom (corner area). However, for 12 mm preform diameter, the thickness of bottle can be visualized clearly where the thickness was getting thinner from the neck to bottom but growing thicker from bottom to base.

Initially at the finish, the thickness was found to drop rapidly until the shoulder part. It then found to remain constant or drops gradually through the body until bottom and rise significantly throughout the base. The base should be thick satisfactory to eliminate the problem related with drop impact strength. However, if the base is over-thick, it will become fracture and resulting in reduction of drop impact strength. The finish should be thick enough to withstand the pressure come from the blowing nozzle during the blow molding process and the torque used to tighten the bottle cap [12].

Table 3. Summary of wall thickness distribution for different preform diameter.

| Preform Diameter (mm) | Percentage of distribution (%) | Minimum wall thickness (mm) |
|-----------------------|--------------------------------|----------------------------|
|                       | Over than 1 mm | Less than 1 mm |                        |
| 4                     | 83.33          | 16.67          | 0.2                     |
| 6                     | 100            | 0              | 1.3                     |
| 8                     | 100            | 0              | 2.0                     |
| 10                    | 100            | 0              | 2.7                     |
| 12                    | 100            | 0              | 2.7                     |

Table 3 shows the summary of results collected for each preform diameter. As can be seen, only 4 mm preform diameter presented wall thickness below than 1 mm. Therefore, this value of preform diameter should be to prevent very small thickness of wall in PET bottle. On the other hand, at least 6 mm preform diameter can permit the wall thickness It was found that only 4 mm preform diameter presents wall thickness below than 1 mm. On the other hand, at least 6 mm preform diameter can permit the wall thickness at least 1.3 mm i.e. at the shoulder area.1.3 mm i.e. at the shoulder area. This suggest that preform diameter of 4 to 6 mm can be further investigated to get the smallest 1.0 mm wall thickness.

3.2. Contour of thickness at time

As the fluid preform is moving towards the bottle mold, the thickness is inflated and the color represents the distribution of thickness over the time. The contour of thickness at different time step have displayed
clearly the direction of the stretching force applied to the preform which included the first step until the final step that form the shape of the mold [11].

As shown in figure 4, it can be observed clearly at the final time step that the thickness was found the smallest at the bottom corner of the bottle where the preform has been the most extended and had a largest plastic stretching in circumferential and longitudinal directions. But the thickness was observed the largest at the top. This can be attributed to the deformation that was less take place in a small diameter.

Furthermore, it can be seen at the final time-step in all figures that the thinnest part was found at the corner, where bottom of the bottles confide fundamentally on the shape and dimensions of the cavity mold. It also lies on shifting the degrees of individual areas where the preform was stretched as well as the contact between preform and the mold at different times. Therefore, the correlation between the final thickness profile of the bottle and preform diameter which acts as the shape of cavity mold is probably fluctuating depends on the desired final shape of bottle.

Figure 4. Contour of thickness at different TS (time step) for (a) 4 mm, (b) 6 mm, (c) 8 mm and (d) 10 mm preform diameter.

3.3. Contour of pressure at time-step

Figure 5. Contour of pressure at final-step for (a) 4 mm, (b) 6 mm, (c) 8 mm, (d) 10 mm and (e) 12 mm preform diameter.

Figure 6. Contour of velocities distribution in x-direction at final-step for (a) 4 mm, (b) 6 mm, (c) 8 mm, (d) 10 mm and (e) 12 mm preform diameter.
In order to present the results of polymer pressure field within the mold, the contour plots of pressure at different time steps were extracted. Generally, the magnitude of stress was interrelated to the stretching force at boundary. The stretching force will then affect the processing time directly for forming a complete PET bottle [8].

A general observation to figure 5 suggests that increasing preform diameter increased the pressure at the final step. It was also revealed that the 4 mm diameter preform has the least of stress distribution, where the contour of minimum stress were found. For 12 mm diameter preform, it has the most stress distribution as can be confirmed from the maximum stress indicated in the figure.

4. Conclusion

A simulation study in injection stretch blow molding has been conducted using ANSYS Polyflow. The study was mainly performed to evaluate the wall thickness distribution of PET bottle for different diameter of initial preform. It was found that only 4 mm preform diameter presents wall thickness below than 1 mm. On the other hand, at least 6 mm preform diameter can permit the wall thickness at least 1.3 mm i.e. at the shoulder area. The thickness was found the smallest at the bottom corner of the bottle where the preform has been the most extended and had a largest plastic stretching in circumferential and longitudinal directions. But the thickness was observed the largest at the top.

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