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A simulation study of the effect of preform cooling time in injection stretch blow molding

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ABSTRACT

Plastic bottles are most commonly made from poly(ethylene terephthalate) (PET) by injection stretch blow molding (ISBM). The required bottle performance criteria vary with its application but typically include top load strength, burst strength, and barrier properties, each of which is influenced by the bottle processing parameters. Experimental process optimization is time-consuming and costly, and computer modeling methods now offer a viable alternative.

In this study, the optimum cooling time of the bottle preform was determined by conducting structural analysis of the actual bottles. On the other hand, the process simulation and the simulation of structural analysis of the PET fruit juice bottles were conducted under the same conditions with those from actual bottles produced. The experimental results were compared with simulation results. The structural simulation studies validated most of the experimental findings. The discrepancy between the experimental study and the simulation predictions were explained.

1. Introduction

Polyethylene terephthalate (PET) is the material of choice for bottles due to its excellent clarity, good mechanical and barrier properties, and ease of processing. The bottles are generally made by injection stretch blow molding (ISBM), in which an injection molded preform is deformed radially by air pressure and axially by a stretch rod. The air pressure load is applied in two stages; pre-blow and final-blow. The pre-blow forms most of the bottle shape while the final-blow exerts a higher pressure to produce the final detailed form. Production processing conditions and the PET properties affect the final bottle quality, typically defined by burst strength, top load strength, and barrier properties.

Top-load strength assesses the overall durability of the bottles necessary for filling and stacking during manufacturing, and in subsequent storage and distribution. Burst strength, the pressure at which the bottle bursts; is to ensure the bottles do not blow up at the filling stage, and filled bottles do not expand excessively during storage or during the pasteurization process. Barrier properties which are related to morphology of the bottles, determines the shelf life of the product as it controls gas permeation through the bottle walls.

The preform temperature and temperature profile dictate the clarity and material distribution in the bottle; as well as the ease of processing. Preform cooling time has been established as one of the most important parameters among the operation-adjustable parameters in manufacturing of PET bottles (Rujnic-Sokele et al., 2004). While the other parameters, in particular blow pressure and stretch rod speed may also be influential, preform temperature profile provides a practical means of redistributing material so as to achieve uniform wall thickness in the final product. Also, in plastics packaging industry, it is a common practice to vary the preform temperature in order to achieve uniform bottle wall thickness; this is particularly relevant for the two-stage injection stretch blow molding machines, where the preform is re-heated prior to the stretch/blow stage. Therefore, there are numerous experimental and simulation studies of injection stretch blow molding process which incorporates the preform temperature and temperature profile. In one of the earlier studies of injection stretch blow molding, McEvoy et al. (1998) used commercially available software (ABAQUS) and simulated various axi-symmetric PET bottles. The temperature range for PET preform in bottle production process ranged from 90 to 110 °C with preform top temperature being lower than that of the main body to encourage more material movement into the bottle base. Other processing parameters, namely the magnitude of the blow pressure; the timing of the

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blow relative to the stretch rod motion, and stretch rod speed were also studied to improve the simulation predictions in terms of bottle wall thickness. Hartwig and Michaeli (1995) proposed a theoretical model that allows the investigation of the combined effect of thermal preform conditioning and the molding phase on the wall thickness distribution of the bottles. The model which employs a temperature dependant material behavior, takes account of the preform temperature profile both in the axial and radial direction. Pham et al. (2004) developed a visco-hyper-elastic material model to simulate the single-stage injection stretch blow molding process. An optimal preform temperature profile was input based on experimental preform surface temperature. It was assumed that the preform temperature through thickness is approximately close to the experimental surface temperature at the end of conditioning step. However, their simulation results deviated somehow from the experimental data. Yang et al. (2004) introduced a fully coupled temperature-displacement modeling of ISBM of PET bottles with a view to optimize process parameters. The model incorporating heat transfer between the preform, stretch rod and mold successfully predicts the side wall thickness distribution for most part of the bottles studied. In their study, preform surface temperature was measured by means of an infrared camera. The discrepancy between the prediction and the experimental data was attributed to the inaccuracy in recording the actual preform temperature. Visualization of preform deformation during stretching and blowing steps were undertaken by Huang et al. (2007) via a transparent mold. The deformation mechanisms of the PET preform, which are dependent on preform size, geometry and temperature profile, were found to be critical in controlling the bottle wall thickness distribution. In one of the recent studies of the ISBM process, Bordival et al. (2009) proposed a practical methodology to numerically optimize the temperature distribution of the preform in order to provide a uniform thickness for the bottle in a two stage stretch blow molding machine. They achieved good agreement in the trend between temperature profile experimentally determined within industrial conditions and the temperature distribution computed using their numerical optimization method. However, they did not optimize the process parameters of the heating system. We also studied the effect of ISBM process parameters and the preform design on the bottle properties (Demirel and Daver, 2009); the process parameters comprising the magnitude of the blow pressure, the timing of the blow pressure activation relative to the stretch rod motion were studied to improve the simulation predictions in terms of bottle wall thickness (Demirel and Daver, 2012).

In this simulation study, we focused on the effect of preform cooling time on the bottles in terms of burst strength and top-load strength and optimized the ISBM process based on cooling time of the bottle's preform i.e. preform temperature profile. In the first stage of the work, a series of 350 ml PET fruit juice bottles were injection stretch blow molded at different preform cooling times and the bottles were tested physically for burst strength and top load strength. In the second stage, the Blowview Software was used to simulate the processing of bottles at different preform cooling times. The processing conditions chosen for the simulation were provided by the physical processing stage of the work. Subsequently, the ANSYS finite element analysis software was used for structural analysis of each simulated bottle to assess the top load and burst strength. Masood and KeshavaMurthy (2005) used a similar approach in analysis and optimization of a 15 l collapsible PET water bottle. They used parametric and finite-element modelling software. In the structural analysis they used a constant Young's Modulus value to define the material properties PET. In our study we used local, microstructure dependant, moduli along the arc-length of the bottle to account for different crystallinity and molecular orientation as a result of the preform deformation process (Daver et al., 2012).

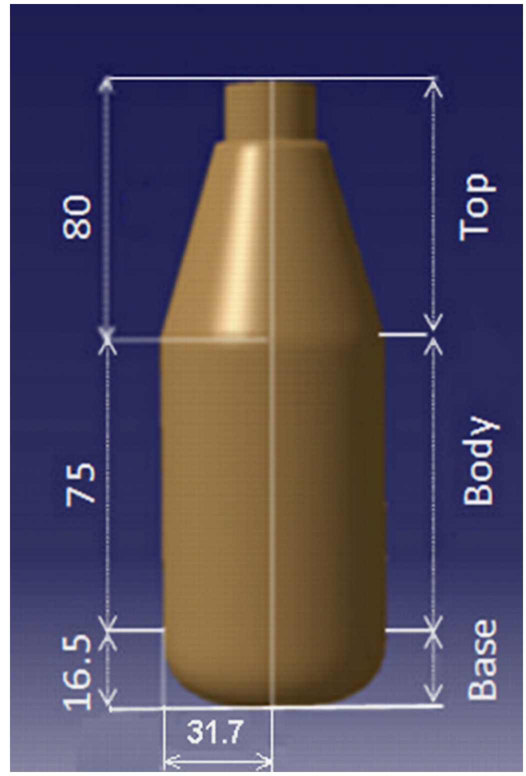

Fig. 1. CAD model of bottle mold (in mm).

2. Experimental

2.1. Material

The PET material used in the simulation study was SKY PET 2180 food grade resin from Leading Synthetics Pty Ltd (Australia) and the visco-hyper-elastic material model was employed in modeling of the injection stretch blow molding process. The model has been developed by Pham et al. (2004) to represent the behavior of PET during the injection stretch blow molding process.

2.2. Bottle mold and preform design

The bottle mold used in this study is shown in Fig. 1. The preform was generated by Blowview version 8.4 (Fig. 2). Fig. 3 shows a typical temperature profile of a preform just before it is stretched and blown into the bottle mold. The preform temperature profile was defined by three points Sp1, Sp2, Sp3 recorded by the thermal imaging camera. The temperature profiles following the preform cooling times of 2, 2.5, 3, 3.5 and 4 s are shown in Table 1; this experimental data was input to the simulation studies.

Table 1
Preform temperature profile following different preform cooling times.

Cooling time (s)	Preform temperature profile (°C)		
	Sp 1	Sp 2	Sp 3
2.0	126	117	107
2.5	122	114	102
3.0	118	110	98.0
3.5	114	106	95.5
4.0	110	103	92.4