Available online at www.sciencedirect.com
SCIENCE DIRECT
NDT&E International 38 (2005) 433–441
NDT&E international
www.elsevier.com/locate/ndteint

Understanding heat transfer mechanisms during the cooling phase of blow molding using infrared thermography

A. Bendada[a,*], F. Erchiqui[b], A. Kipping[c]

[a]National Research Council of Canada, Industrial Materials Institute, 75 De Mortgane, Boucherville, Que., Canada J4B 6Y4
[b]University of Quebec in Abitibi-Temiscamingue, 445 Université Blvd., Rouyn-Noranda, Que., Canada J9X 5E4
[c]University of Siegen, Paul-Bonatz Strasse 9-11, Siegen 57068, Germany

Received 15 June 2004; accepted 25 November 2004
Available online 24 February 2005

Abstract

The cooling phase of the extrusion blow molding process has a large influence on the cycle time of the process as well as on the properties and quality of the molded products. A better understanding of the heat transfer mechanisms occurring during the cooling phase will help in the optimization of both mold cooling channels and operating conditions. A continuous extrusion blow molding machine and a rectangular bottle (motor oil type) mold were used to produce bottles. A high density polyethylene (HDPE) and a metallocene polyethylene (mPE) having different rheological properties were tested. Melt and mold temperatures, cooling time, inflating pressure and die gap were varied systematically. An infrared camera was used to measure the temperature distribution of the plastic part just after mold opening as well as after part ejection. The wall thickness and dimensions of the bottles of the finished parts were measured in order to determine the shrinkage and warpage. Finally, the infrared temperature fingerprints were used to explain what happens during the cooling phase and correlated with the final part characteristics.

Keywords: Blow molding; Cooling; Infrared thermography; Polymer processing

1. Introduction

In the extrusion blow molding of medium size bottles, the cooling stage represents a substantial part of the overall cycle and has a profound effect on the microstructure development and on the ultimate properties of the molded article. During the cooling of the blown part whilst in the mold, heat is removed both by forced convection (polymer/air interface at the internal wall) and conduction (polymer/metal interface at the mold wall). Once the mold opens, the part will continue to cool from both surfaces by natural convection. Several authors [1–4] have developed numerical algorithms for the predictions of the temperature profiles in the parts. Their efforts have been of limited value due to the uncertainty in the values of heat transfer coefficients used to represent the different heat transfer mechanisms. For these reasons infrared thermography presents itself as a complementary technique capable of mapping the thermal history of blow molded parts during the different stages of the cooling process [5–7].

2. Experimental setup

The parametric study was done on a continuous extrusion blow molding machine (Battenfeld-Fischer FBZ1000), equipped with a motor oil type bottle mold. The mold is modular and has five interchangeable parts. The cavity is made of a top block, a middle block and a bottom block, each with its own cooling circuit. The three blocks are mounted onto a back plate and within the middle block an exchangeable insert is located (Fig. 1). The mold cavity has a height of 220 mm, a width of 100 mm and a depth of 50 mm. In this study, a flat insert was used in the middle block to ensure a complete contact between plastic and mold. A diverging die ($\phi = 30$ mm) was used in this study.

* Corresponding author. Tel.: +1 450 641 5241; fax: +1 450 641 5106.
E-mail address: akim.bendada@imi.cnrc-nrc.gc.ca (A. Bendada).

0963-8695/$ - see front matter Crown Copyright © 2005 Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.ndteint.2004.11.007

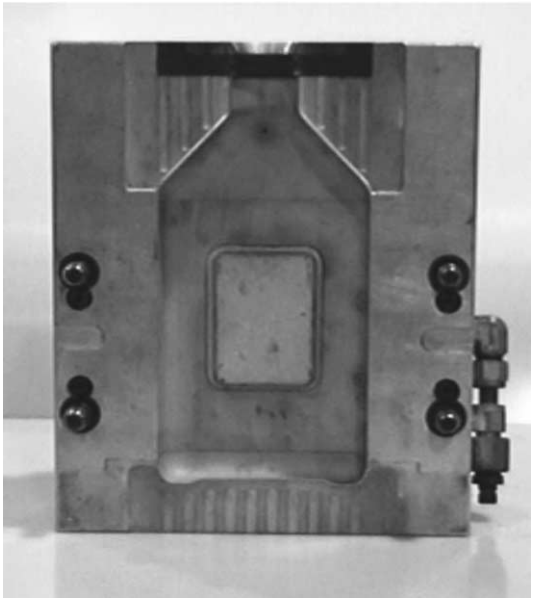

Fig. 1. Mold configuration (cavity and cooling lines).

The machine set-up enables to vary several operating parameters such as die gap, melt temperature, inflation pressure, cooling time, and temperature of the coolant liquid.

The temperature distribution of the plastic bottle was measured directly after mold opening, while remaining attached to the blow pin. An AGEMA 900 LW infrared camera was used. The thermographs covered an area of the bottle described as follows: short side-corner-wide side. The temperature measurement through an infrared camera is a non-contact technique, so that the recorded temperature itself is not disturbed by the measurement [8]. With this technique, both the temperature level and its distribution on the part surface can be observed. The infrared camera is equipped with a HgCdTe sensor; its spectral response is centered around 8–12 μm in the far infrared spectrum. It has a sensitivity of 0.08 at 30 °C, and a repeatability of 0.5%. The infrared frames of 68 lines of 272 columns are stored in real time at a rate of 30 Hz on a hard disk for subsequent processing. Due to the polymer semi-transparency to infrared radiation, the infrared camera was only able to provide thermal information about the process in terms of an average or bulk temperature, but not about the surface temperature or the detailed temperature distribution inside the part [9]. During the measurements, precautions have been taken to overcome spurious radiation (transmitted or reflected) from nearby hot objects. The overall experimental set-up (blow molding machine and camera) is shown in Fig. 2.

After demolding, the subsequent cooling of the bottles was monitored by placing the bottles in a reference support. Furthermore, the solid bottles were also photographed placed in this support (constant camera angle) in order to measure their dimensions and dimensional stability. This allowed the comparison between differently produced bottles by superposing the images on a grid. Finally, the wall thickness of the bottles is measured along the circumference, 80 mm from the bottom.

3. Materials

Two different materials were used in this study. A typical blow molding high density polyethylene (HDPE)—

Fig. 2. Experimental setup.