Available online at www.sciencedirect.com
SCIENCE DIRECT®

Polymer Testing 24 (2005) 948–952

POLYMER TESTING

www.elsevier.com/locate/polytest

Test Procedure

A comparative study on extrudate swell ratio of polystyrene in a capillary rheometer and a single screw extruder

N. Sombatsompop *, N.-T. Intawong

Polymer Processing and Flow (P-PROF) Group, School of Energy and Materials, King Mongkut's University of Technology Thonburi (KMUTT), Bangmod, Thungkru, Bangkok 10140, Thailand

Received 13 July 2005; accepted 21 August 2005

Abstract

This article offers a comparative discussion on the extrudate swell ratios and velocity profiles of polystyrene melt flow using the same die with two different machines which were a constant-rate capillary rheometer and a single screw extruder. The swelling ratio and melt velocity profiles were simultaneously measured at different positions across the die diameter, with and without application of a magnetic field to the die. The results suggested that the overall swell ratio of the PS melt measured in the extruder was greater than that in the rheometer, this being caused by the differences in the flow properties of the melt in these two machines. The discrepancies in the radial extrudate swell profiles from the rheometer and extruder could be explained by the velocity profile development. When an electro-magnetized die was used, the swelling ratio of the melt changed with magnetic flux density and was affected by the size of the machinery used.

Keywords: Extrudate swell; Rheology; Rheometer; Extrusion process; Flow properties

1. Introduction

Under normal processing conditions, polymer melts exhibit viscoelastic behaviour and their rheological characteristics depend on how the polymer melt is being deformed. The extent of deformation and deformation history are strongly affected by the flow geometry, which is determined by the type of deformation [1]. The most common test apparatus used for the determination of the flow properties of polymer melts for any processing technique is the extrusion capillary rheometer [2]. However, it has been evident that the flow property results produced in the capillary Rheometer are dependent on the design of the apparatus, the same die giving different results when used in different apparatus designs [3,4]. In the extrusion process, the swell of he polymer melt is considered one of the main factors to determine quality and dimensions of the final product. Most experimental data are only available for the overall extrudate swell (the ratio of the extrudate size to the die size), and the explanation for the change in extrudate swell is usually associated with the recoverable elastic deformation developed during flow through the die [1]. Scientific evidence [5,6] has clearly suggested that velocity profiles and die swell were closely related, but most work in the literature has been carried out with these two parameters separately and theoretically.

This present article aimed to continue from two recent works [7,8] on measurements of overall and radial extrudate swell and velocity profiles of PS melt flowing in the die of a constant-rate capillary

* Corresponding author. Tel.: +662 470 8645; fax: +662 470 8614.

E-mail address: narongrit.som@kmutt.ac.th (N. Sombatsompop).

0142-9418/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.polymertesting.2005.08.008

rheometer. The first publication [7] proposed a novel experimental technique, so-called Parallel Coextrusion Technique (PCT), to *simultaneously* measure the radial swell and the velocity profiles of the melt and the second publication [8] introduced a novel *electro-magnetized die* for controlling the extrudate swell. In this present article, we attempt to offer comparative discussion on the extrudate swell ratios and velocity profiles of the PS melt flowing using the same die with two different processing machines, these being a constant-rate capillary rheometer (CR) and a single screw extruder (SSE). Such comparison had never been reported in literature, especially the swelling of the extrudate being measured at different positions across the die diameter and under a magnetic field.

2. Experimental

2.1. Raw material

All tests used polystyrene (Styron656D 267) with a melt flow rate of 7 and a density of 1.350 g/cm^3, supplied in granular form by Siam Polystyrene Co., Ltd (BKK, Thailand).

2.2. Experimental technique and apparatus

A circular cross-section die with 64×10^{-3} m in length and 5×10^{-3} m in diameter was used in this work, the design and dimensions of the die used being given in previous works [7,8]. The experimental arrangement was that the circular die system was connected at the bottom of the CR and SSE machines, the size and details of the manufacturers for the rheometer being given in previous published work [7], whereas the single screw extruder (ThermoHaake PolyDrive Extruder) used had a barrel length-to-diameter (L/D) ratio of 200/25 mm/mm. The temperature profile on the extruder length was 170, 180, and 190 °C. The die temperature of both machines used was varied from 200 to 230 °C.

The experimental technique used for the measurements of the radial extrudate swell and velocity profiles was a Parallel Co-extrusion Technique (PCT), the detail of the technique being already published and found elsewhere [7]. The PCT was based on a parallel co-extrusion of colored melt-layers into an uncolored melt-stream from the barrel into and out of the circular cross-section die. The radial extrudate swell ratio values (B_r) were obtained by comparing the thickness of the colored layer of the extrudate outside the die, for a given reduced radius (r/R) position across the die diameter. The r/R range of interest used in this work was from 0.0 to 0.86. The velocity profile, which was also measured by the PCT technique, was based on monitoring a relatively small and light foreign object (corn particles) flowing along the melt streams (colored layers), and the measurements were carried out by recording the times taken for the corn particle loaded into the melt layers to travel for a given distance in the die (10 mm before the die exit). It should be noted that the extrudate swell ratio and velocity profiles at any radial positions across the die were averaged from five determinations, and were obtained in the piston displacement range of 85–92 mm down the barrel. Flow curves of the melt was evaluated in both machines using the same die and test conditions as used in the swell and velocity profile measurements, the experimental procedures being detailed elsewhere [9].

Another novelty offered in this work was the application of an electro-magnetic field to the die for the extrudate swell measurement. The design and manufacture of the electro-magnetized die were detailed in previous work [8]. In this work, we studied the extrudate swell and velocity profile results between the capillary rheometer and the single-screw extruder in the die with and without the magnetic field (varying magnetic flux densities from 0.75 to 1.85 T) for different die temperatures (200–230 °C) and wall shear rates (5.1, 8.5 and 17.1 s^{-1}).

3. Results and discussion

Fig. 1 shows the overall extrudate swell values of the PS as a function of wall shear rate in the capillary

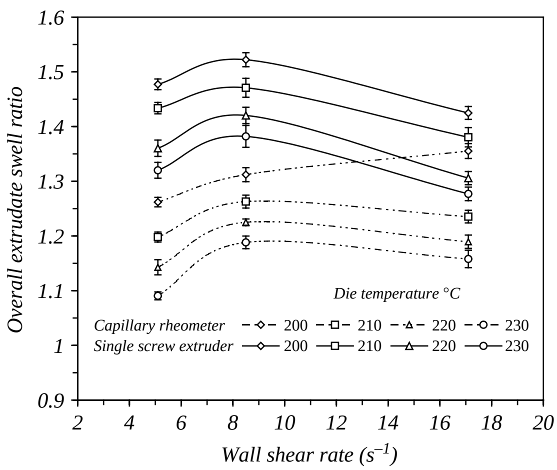

Fig. 1. Overall extrudate swell of PS melt as a function of wall shear rate in the capillary rheometer and extruder for different die temperatures.