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AN INVESTIGATION OF THE PARISON SAGGING BEHAVIOUR DURING THE EXTRUSION BLOW MOULDING OF COPOLYESTER PETG

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ABSTRACT

The shear and elongational rheological behaviours of a copolyester thermoplastic were determined. The copolyester was then extrusion blow moulded into bottles. The parison extrusion behaviour was studied as the output rate and melt temperature were varied. The inflation behaviour was studied as a function of the inflation pressure. The processing behaviour was correlated to the rheological properties of the polymer melt. A mathematical model of the extrusion blow moulding process developed for polyolefins was tested to verify its application to the copolyester material. From the experimental results it has been shown that the copolyester has suitable rheological behaviour for the extrusion blow moulding process. The process model would require additional parameters to be considered before it could be used for prediction of copolyester melt behaviour in extrusion blow moulding.

INTRODUCTION

Extrusion blow moulding is a process used to manufacture hollow articles from plastics materials, see Fig.1. A thick walled tube of plastic melt, known as a "parison" is extruded from a die vertically downwards between the two halves of an open bottle mould. The mould is closed and seals off the ends of the parison, one end being clamped around a spigot through which compressed air is pumped to inflate the parison into the shape of the mould. The mould is water-cooled and when the moulding has solidified the mould is opened, the moulded bottle removed, and the cycle restarts.

Control of the parison geometry is crucial for obtaining the correct dimensions of the end product. This is complicated by the effects of elastic recovery and gravity changing the shape of the molten parison. The elastic recovery of the melt results in swelling of the parison diameter and thickness and also in axial recovery known as "bounce". Parison sagging is drawdown of the melt away from the extruder die due to the effects of gravity. The sagging increases with time during extrusion, due to the increasing mass of the parison. After extrusion stops, the sagging further accelerates due to the parison cross-section at the die becoming smaller, as sagging takes place, increasing the stress at the die lips. Sagging results in the parison thickness tapering down towards the die. The elastic recovery and sagging have opposing effects on the deformation of the parison.

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elongation. The values obtained were:

$$\begin{aligned} \gamma_R &= 1.8 \\ \varepsilon_R &= 0.52 \\ B_{SR}.B_{SH} &= 1.40 \\ B_{ER}.B_{EH} &= 1.48 \end{aligned}$$

The elongational swell value ($B_{ER}.B_{EH}$) was used as it was the greater than the corresponding shear value ($B_{SR}.B_{SH}$); the two values are not additional and only the greater value is used.[7]

The uniaxial elongational stress growth function data for PETG 6763 was determined using an elongational rheometer (Rutherford). This is aniaxial end-separation instrument of the Munstedt type.[8] The specimens used were injection moulded oval hoops that had bulky ends and narrow sides, giving a double dumb bell shape. The specimen shape prevents drawing of the specimens in the clamp regions, and allows for rapid placement on the specimen holders, reducing heat loss from the instrument during the setting up period. The PETG 6763 was dried in a dehumidifying hopper (Conair Churchill) before being injection moulded (Negri Bossi N55). The specimens were moulded using a high mould temperature and long cycle times to ensure complete relaxation of any molecular orientation in the mouldings.

The rheometer construction and operation have been described elsewhere.[5,9,10] In this work the instrument was used in constant strain-rate mode, with the stress measured as a function of time. The specimens were preheated for 6 minutes in the rheometer prior to testing. The melt density of the polymer melt was similar to that of the silicone oil in the instrument and so the oil supported the melt preventing sagging. The data for PETG 6763 at 170°C are shown in Fig.3.

Extrusion Blow Moulding

The PETG 6763 was extrusion blow moulded on a commercial machine (Hayssen Monablow 2070) fitted with a polyethylene screw, into a 1 pint bottle mould. Two melt temperatures and two screw speeds were used to prepare four sets of data. The polymer was dried prior to extrusion. The parison extrusion was filmed using video equipment and measurements of parison sag were made from the video recordings, using a freeze-frame facility. A scale was fixed to the machine behind the open mould so that the length of the parison could be measured as a function of time. A stop-clock was kept continuously in the frame of the film.

The parisons were cut-off from the extruder die and quenched in a water bath. The quenched parisons were weighed. The output rate (Q) was determined from eqn. (5), by extruding for a given time ($t_{extrusion}$) and then weighing the quenched parison (W).

$$Q = W / (\rho . t_{extrusion}) \qquad (5)$$

A series of bottle inflation experiments were also conducted, the inflation air pressure being varied. The bottle quality was assessed visually, using the criteria if incomplete bottle shape or undefined ridges formed at the bottle shoulders as "under-inflated"; and the presence of thin walled areas or burst bottles as "over-inflated"; and the absence of the above mentioned visual defects as "satisfactory".

PROCESS MODEL

The model for extrusion blow moulding used in this work was developed for use with high density polyethylene and polypropylene.[3] The model requires the use of stress growth function data and die swell data. These data for PETG 6763 have been determined in our laboratory as described earlier, Fig.3 shows the stress growth function data.

The model considers the parison deformation as consisting of three components: swelling, sagging during extrusion, and sagging after complete extrusion. The sagging and swelling during extrusion are determined from eqn. (6):

$$L_{(N+1)} = V_d.(t - N\Delta t) \,/\, B_R(\Delta t/2).B_H(\Delta t/2) \qquad (6)$$

where ($L_{(N+1)}$) is the length of parison element (N+1), (V_d) is the time average velocity at the die, (t) is the extrusion time, (Δt) is the time interval for extruding each element, (B_R) and (B_H) are the swell ratios for the diameter and the thickness of the parison.

The sagging after extrusion is complete is considered as the sum of the element deformations, defined by eqn. (7):

$$1/Z_{i(ti)} = 1/Z_{i(ti=0)} - 1/2\, \rho\, g(i-1) \int_0^t dt'/\, \lambda_{(ti,t')} \qquad (7)$$

where (Z_i) is the length element (i) would have reached if there were no swell, (ti) is the time that has elapsed since element (i) was completely extruded, and (λ) is the elongational stress growth function. This deformation can be adjusted to account for swell using eqn. (8) and added to eqn.(7) to give the total parison length, eqn.(9):

$$Li = Z_{i(ti)}/\, B_{R(ti + \Delta t/2)}.B_{H(ti + \Delta t/2)} \qquad (8)$$

$$L(t) = [V_d.(t - N\Delta t) \,/\, B_{R(\Delta t/2)}.B_{H(\Delta t/2)}] + \sum_{i=0}^{n} \qquad (9)$$

RESULTS AND DISCUSSION

Shear rheology of PETG 6763

Fig.2 shows the viscosity curves of PETG 6763 melt at temperatures from 170°C to 260°C. The curves show near-Newtonian behaviour (viscosity independent of shear rate) at low shear rates and shear thinning behaviour (psuedoplasticity) at higher shear rates. The near-Newtonian viscosity decreases with melt temperature in a manner that can be fitted to an Arrhenius type equation to yield an activation energy of 76.57kJ/mole. The rate of molecular disentanglement exceeds that for re-entanglement at a higher shear rate with increasing temperature, this is when the melt stops behaving in a Newtonian manner and shows psuedoplastic behaviour. At high shear rates the viscosity curves at different tempertures converge showing less temperature sensitivity.

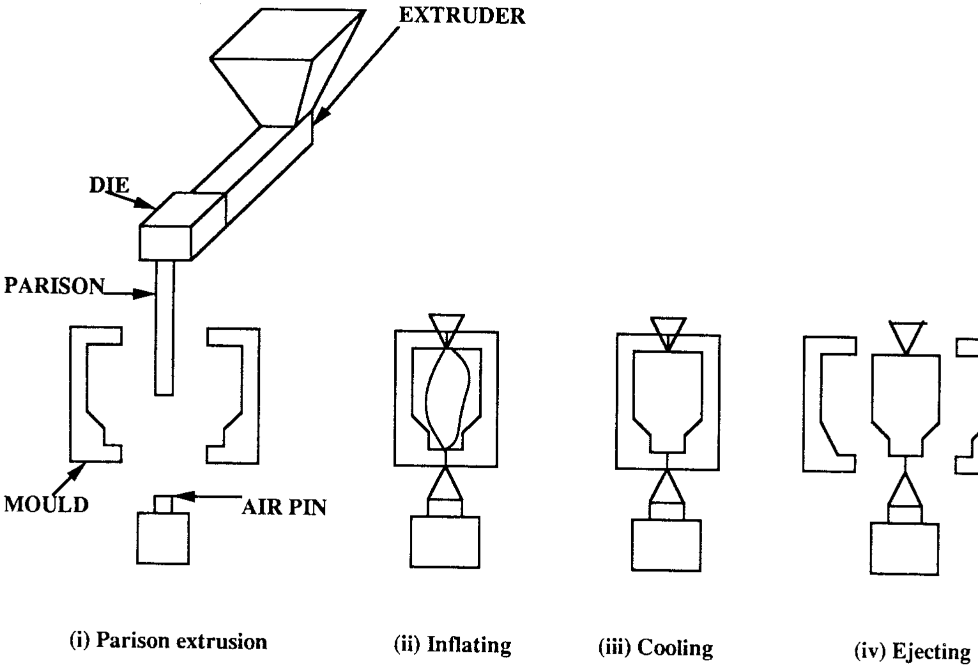

Fig. 1. Extrusion Blow Moulding Process.

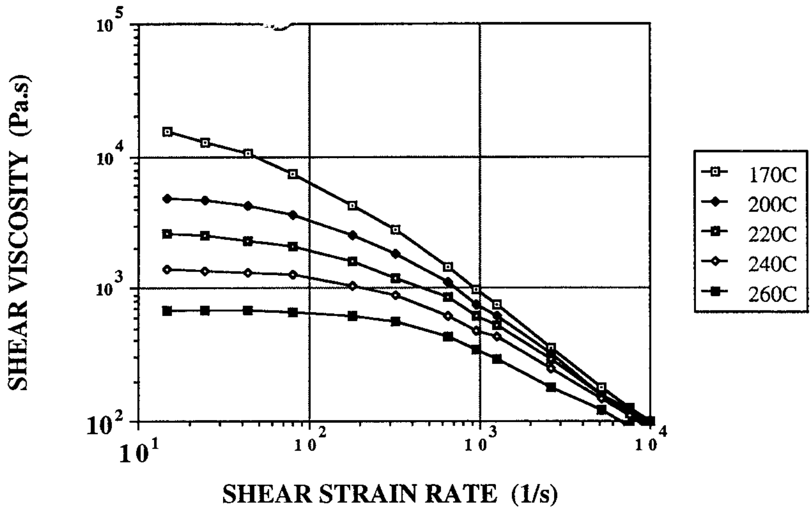

Fig. 2. Shear Rheology of PETG 6763. 6763.ess.

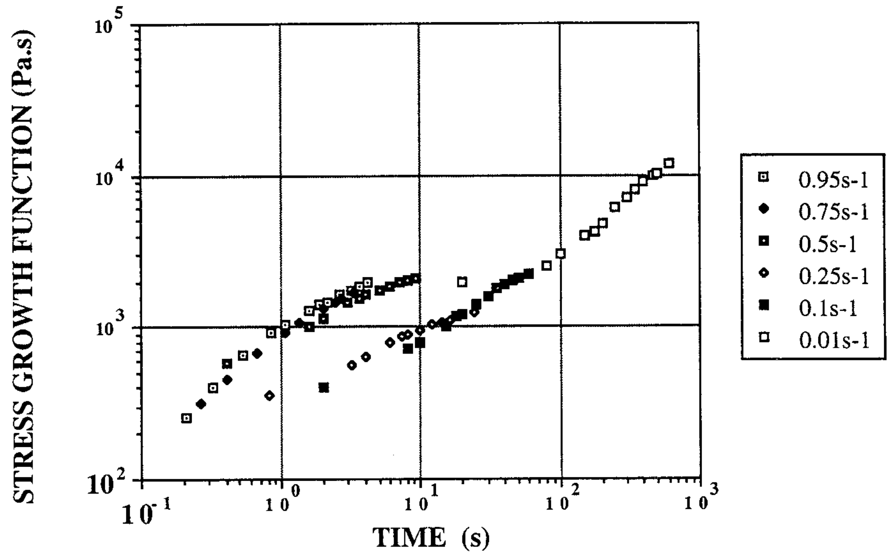

Fig. 3. Elongational Rheology of PETG 6763 at 170° C.

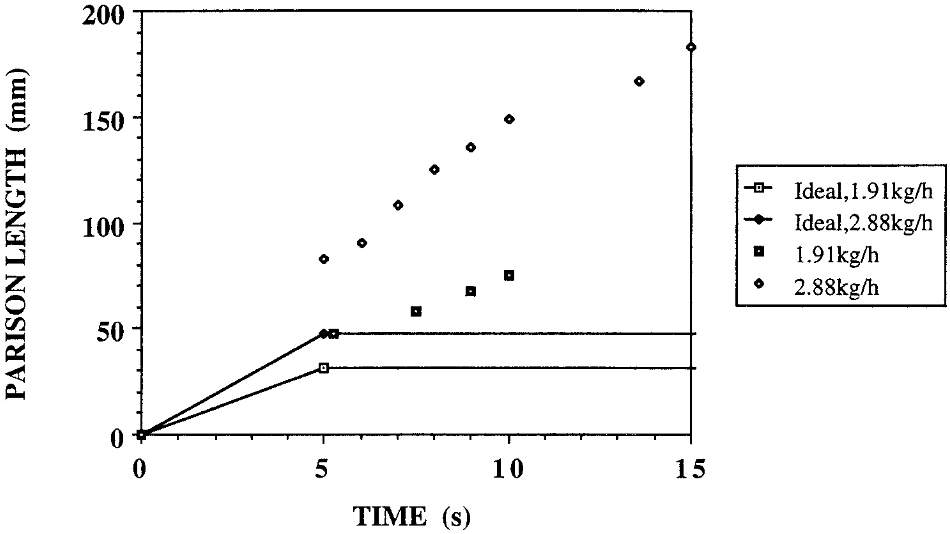

Fig. 4. PETG 6763 Extrusion at 170° C.

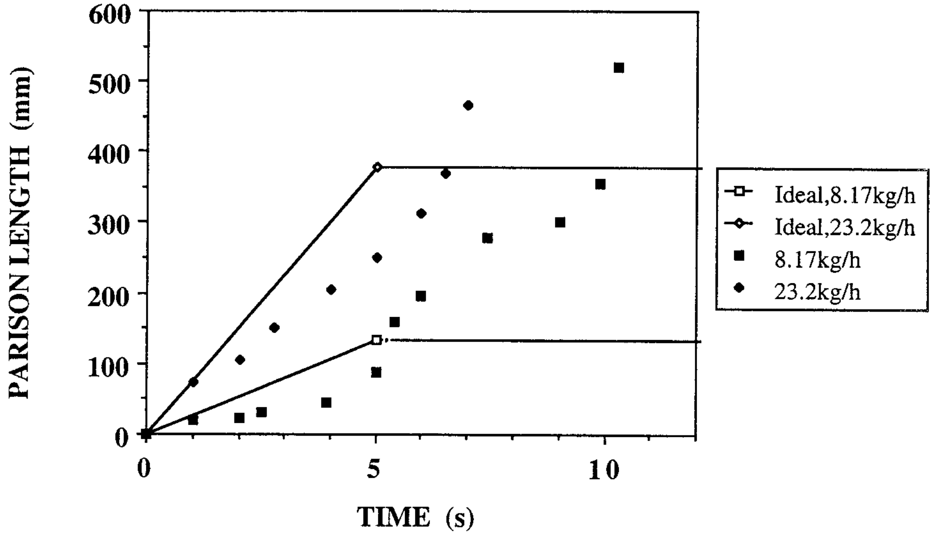

Fig. 5. PETG 6763 Extrusion at 200° C.

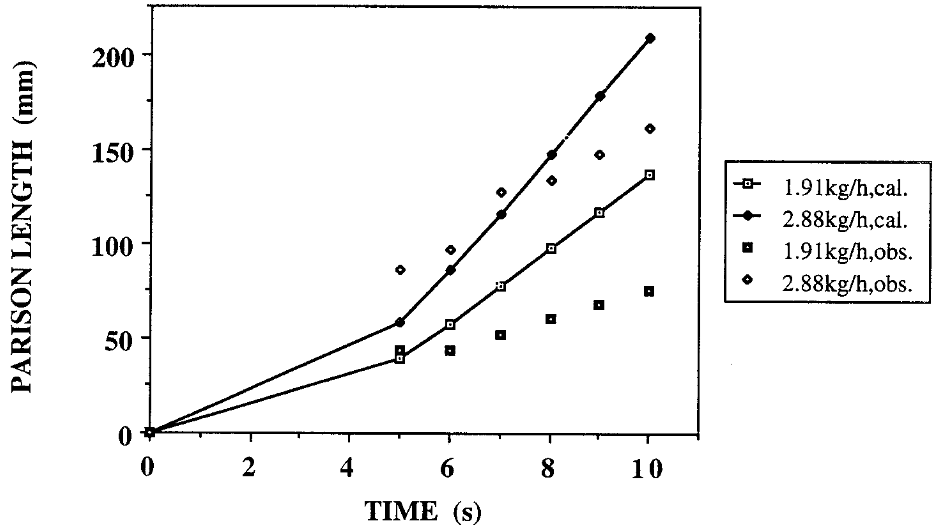

Fig. 6. Comparison of Observed and Model Data.

The shear viscosity values are sufficiently high at low shear rates and low at high shear rates to allow the polymer to be extruded into a parison having sufficient melt strength to avoid excessive sagging and to avoid melt fracture during extrusion.[12]

Elongational rheology of PETG 6763

Fig.3 shows the stress growth function data (elongational viscosity) of PETG 6763 melt at 170°C as a function of time at different elongation rates. It can be seen that at high elongation rates and short times the stress growth is very rapid due to the resistance of the randomly arranged entangled polymer melt molecules to the uniaxial re-orientation. After the orientation has taken place the stress growth is slower and steady due to the resistance of the molecules to chain slippage. At slower elongation rates the stress growth rate is almost constant as the molecules offer less resistance to the uniaxial re-orientation, sufficient time for disentanglement being provided and the stress growth rate for chain slippage being similar to that for molecular orientation. The chain slippage stage of deformation has stress growth rates which are similar shown by the parallel arrangement of the curves shown in Fig.3.

The consequence of this uniaxial elongational melt flow behaviour to extrusion blow moulding can be summarised as saying that the tension stiffening nature of the PETG 6763 melt with increasing elongation rate will act to stabilise the parison elongation, i.e. as the tensile stress on the melt increases the parison will have greater resistance to sagging. This is a beneficial characteristic of the melt for this type of processing.

PETG 6763 parison extrusion

The parison extrusion results are shown in Figs.4 and 5. The ideal behaviour is shown by the solid lines this shows the parison length to increase linearly with time during extrusion and to not change after complete extrusion (i.e. no parison sagging, swell, or bounce). The position of the experimental points higher than the ideal parison line in Fig.4 shows that at 170°C sagging occurred during extrusion, increasing with increased parison mass, as well as after extrusion was complete, increasing with decreased cross-sectional area of the melt at the die exit.

Fig.5 shows that at the higher output rates, swelling dominated the parison behaviour during extrusion (experimental points lower than zero deformation line). This is because the polymer had a shorter residence time in the die and therefore had less relaxation time, this resulted in a greater degree of elastic strain recovery. The shear stress at the die was higher which resulted in a greater degree of swelling. After extrusion was complete sagging became dominant. The rate of sagging increased with temperature and output rate, as well as time.

PETG 6763 parison inflation

The quality of the inflated bottles obtained is summarised in Table 1. A reduction in "over inflated" bottles was observed with increasing inflation pressure. The occurrence of both "under-inflated" and "over-inflated" bottles at the same conditions of inflation pressure show that the process was unstable under all the conditions used. Crawford has reported that if the hoop stress exceeds the melt fracture stress of the polymer, then unstable inflation will result.[11] This was found to be the case for the PETG 6763 under the conditions used. The melt fracture stress was determined from the shear rheology experiments to be 0.898MPa at 170°C. The hoop stresses shown in Table 2 were calculated using eqn. (10):

$$\sigma_{HOOP} = P.D/2H \qquad (10)$$

where (σ_{HOOP}) is the hoop stress, (P) is the inflation pressure, (D) is the mould diameter, and (H) is the final parison wall thickness.[11] The final parison wall thickness can be calculated from eqn. (11):

$$H = (B_R)^3 H_d(D_d/D) \qquad (11)$$

where (H_d) is the die gap, and (D_d) is the average die diameter.[11] The final parison wall thickness was calculated to be H= 0.816mm.

Comparison of modelled and observed data

Table 3 shows the data obtained from eqn.(6) and from the experiments for PETG 6763 at 170°C. it can be seen that the calculated values under-estimate the experimentally observed values of parison length during extrusion. A possible reason for this discrepency could be the reduction of melt viscosity due to shear heating during extrusion, which would lead to less swelling and greater parison sagging.

Table 4 and Fig.6 show the data obtained from eqn.(9) and from the experiments for PETG 6763 at 170°C. It can be seen that good agreement was obtained between the predicted and experimentally observed values at the faster output rate, though the calculation generally leads to an over-estimation.

The over-estimation at 1.91kg/h may be due to the elastic recovery effects having been under-estimated, parison bounce in the vertical direction has been ignored and if bounce occurred the parison length would be shorter than predicted. The swell ratio product has been treated simply as being the greater of the two values determined from shear and elongational flows. In extrusion blow moulding dies, both types of flow occur simultaneously and it is possible that some interaction occurs that would increase the overall swell ratio; hence a reduced amount of sagging would be observed in practice compared to that predicted by the model.

TABLE 1. Quality of bottles

Inflation pressure inflated" (Pa)	Percentage of bottles produced			
	"Under inflated"	"Satisfactory"	"Over-inflated"	
			Thin spots	burst
0.034	75	22.5	0	2.5
0.069	60	0	20	20
0.103	50	0	40	10
0.138	35	10	40	15
0.172	25	25	50	0
0.276	20	0	50	30

TABLE 2. Hoop stress for PETG 6763 bottle inflation

Inflation pressure (Pa)	Hoop stress (Pa)
0.034	0.718
0.069	1.436
0.103	2.155
0.138	2.873
0.172	3.591
0.276	5.746

TABLE 3. Parison sagging during extrusion

Output rate (kg/h)	Extrusion time (s)	Calculated parison length (mm)	Observed parison length (mm)
1.91	5	39	44
1.91	10	80	88
1.91	15	122	188
2.88	5	58	86
2.88	10	122	170
2.88	15	184	237

TABLE 4. Parison sagging after extrusion

Extrusion time (s)	Sag time (s)	Calculated parison length (mm)	Observed parison length (mm)
Output rate =1.91kg/h			
5	1	57	44
5	2	77	52
5	3	97	60
5	4	117	68
5	5	137	75
Output rate = 2.88kg/h			
5	1	86	97
5	2	116	127
5	3	147	134
5	4	178	148
5	5	209	161

CONCLUDING REMARKS

PETG 6763 showed melt shear thinning and elongation stiffening rate dependent behaviour at 170°C. The rheological properties make it a suitable polymer for processing by extrusion blow moulding.

The PETG 6763 exhibited parison deformation in extrusion blow moulding due to the effects of elastic recovery and gravity. The rate of sagging increased with output rate, melt temperature and time. The polyolefin model developed by Garcia-Rejon, Dealy and Orbey[3] offered reasonable predictions of parison deformation of PETG 6763 but could be improved, possibly by incorporation of terms for shear heating during extrusion, parison bounce and allowing for possible interaction between the shear and elongational elastic recovery effects.

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