Separation of the Polymer Components in Injection-moulded Polystyrene

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ABSTRACT

The purpose of the present study was to provide experimental evidence for the separation of the polymer components during conventional processing operations. This was achieved by injection moulding two commercial grades of polystyrene (high-flow and low-flow grade) and by characterising the surface and the bulk of the moulded parts by the time-of-flight secondary ion mass spectroscopy (TOF-SIMS) technique. Results indicated that separation of paraffin (according to the TOF-SIMS spectra) to the surface of the high-flow grade mouldings took place.

INTRODUCTION

It is well known that the bulk properties of polymers can be rather different from their surface counterparts[1]. Among different factors contributing to that, the surface composition plays an important role in determining, for example, the optical, adhesive, weathering and general processing properties.

Injection moulding is one of the most important techniques for the mass production of polymeric items. During processing, the complex flow patterns[2] and the high cooling rates are main causes for the textured structure development in the mouldings. Besides that, an applied flow field can induce phenomena such as mixing, de-mixing and phase transitions of the polymer components. An active discussion is in progress to delineate the hydrodynamic[3] and thermodynamic[4] contributions with regard to these flow-induced separation effects.

The purpose of the present work was to provide experimental evidence for separation of polymer components during conventional injection moulding. This was achieved by characterising the surface and bulk (cross-section of the moulded parts) composition of the moulded items by means of the time-of-flight secondary ion mass spectroscopy (TOF-SIMS) analytical technique[5]. Two grades of general-purpose polystyrene (high-flow and low-flow grade) were moulded into a single-gated rectangular mould with a central rectangular core. Due to the geometric constraint of the mould, a weld type of defect was obtained in the mouldings.

MATERIALS

A low-flow grade general purpose polystyrene for injection moulding and extrusion processing (*Polystyrol 168 N*), denoted as GPPS I, and a high-flow, low molar-mass grade for thin-walls injection moulding applications (*Polystyrol 144 C*), denoted as GPPS II, were selected. The materials were supplied by the BASF Group. Table 1 gives the polymer description of the two polystyrenes with regard to the melt volume rate (MVR) and the molar mass characteristic. Other typical properties of the two polystyrenes can be found elsewhere[6].

Table 1. Product description of the two polystyrenes from the supplier.

	MVR [ml/10min]	Molar-mass extent
GPPS I	1,5	High
GPPS II	28	Low

EXPERIMENTAL

Machine, mould cavity and processing

The machine used to mould the test specimens was an ARBURG ALLROUNDER 221M 250-55. A single-gated rectangular mould with a centred rectangular core was used to manufacture the mouldings. The geometry of the mould and the location of the injection gate are schematically shown in Fig. 1. The overall mould wall thickness was 2,0 mm.

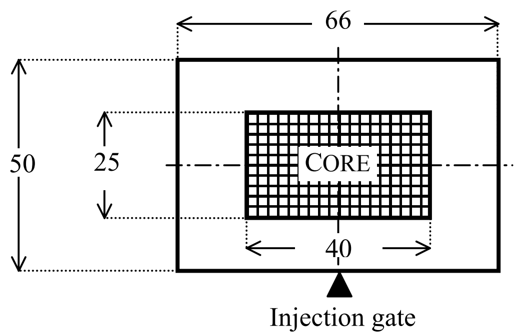

Figure 1. The geometry of the mould cavity. Dimensions in millimetres.

The injection temperatures for GPPS I and GPPS II were set to 230 °C and 210 °C, respectively. The mould temperature was set to 40 °C for both processed polymers. The remaining main processing parameters were selected according to the recommendations of the machine manufacturer and the material supplier (conventional conditions).

TOF-SIMS

The measurements were carried out with a TOF-SIMS IV instrument (Ion-ToF, GmbH, Germany). A pulsed low-energy electron beam was used to minimise surface charges. Positive secondary ions were detected (positive spectra). The other main analysis parameters in Table 2 were used.

Table 2. TOF-SIMS parameters.

Primary ion:	25 keV Ga^+, ≈1 pA
Analysis spots	≈100 × 100 μm^2 (lateral resolution: ≈1 μm)
Typical mass resolution M/ΔM	4000 at the $C_3H_5^+$ peak

The conditions used fulfil the requirements for static-SIMS (SSIMS)[5], i.e. the surface damage caused by the primary ion beam during recording of the spectrum can be neglected.

The entire moulding could be placed on the sample holder of the TOF-SIMS apparatus with regard to the surface studies. The specimens for the bulk analysis were instead prepared by cross sectioning the mouldings in two regions of the moulding, i.e. the injection gate region and the terminal region, opposite the gate, where the two flow fronts created by the core within the mould (Fig. 1) form a weld line (weld region).

RESULTS AND DISCUSSION

The characteristic polystyrene fingerprint[7] dominates the surface and the bulk of the mouldings obtained with the low-flow polystyrene and the bulk of the high-flow grade mouldings, see Fig. 2 (top). The sodium (Na^+) contaminant in Fig. 2 (top) was believed to be of external origin because of its occasional recurrence.

Surprisingly, the surface of the mouldings manufactured with the high flow grade is clearly not dominated by polystyrene, Fig. 2 (bottom). A fragmentation pattern of the type C_nH_{2n-1}

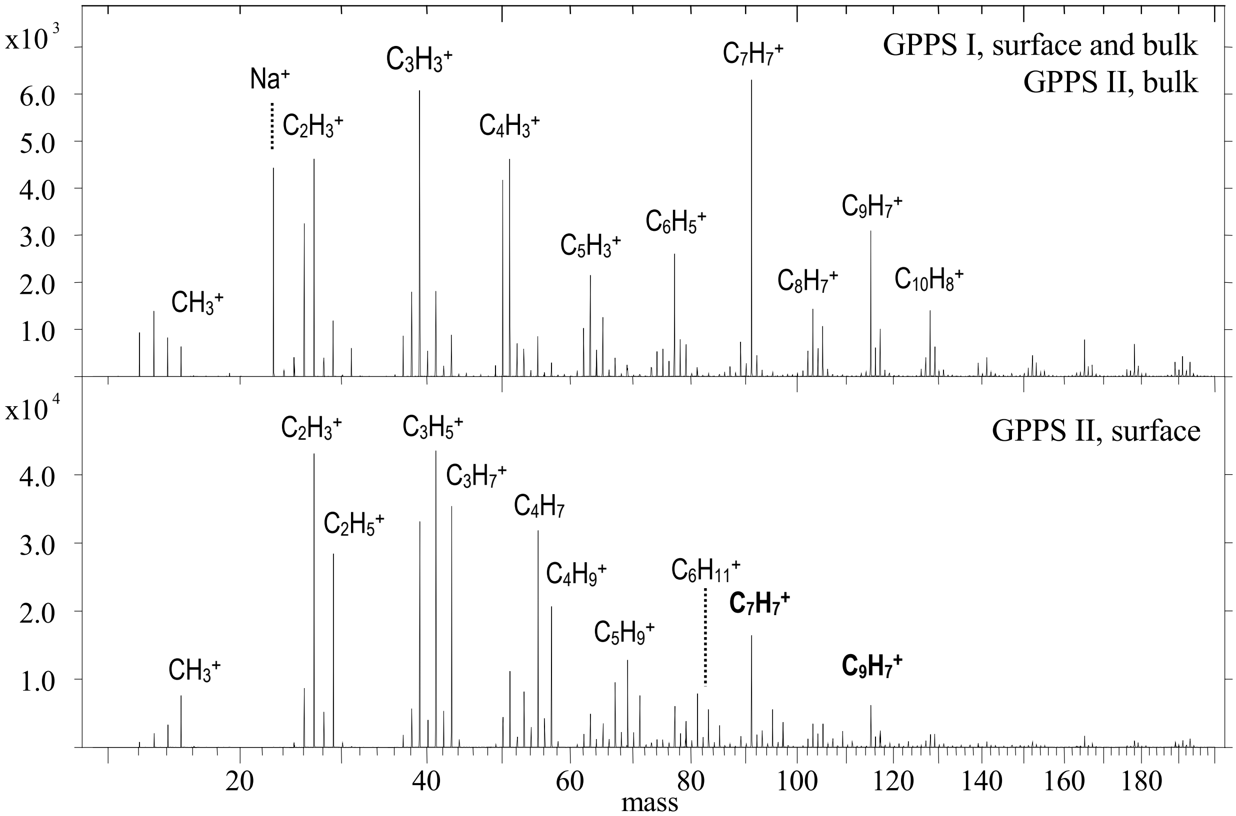

Figure 2. TOF-SIMS surface spectra of the mouldings obtained with GPPS I (top) and GPPS II (bottom).

(C_nH_{2n+1}), typical of the polyolefins[7], appears. Data on polyolefins with different molar masses[8] indicate that the spectrum in Fig. 2 (bottom) is consistent with that of a low molar-mass (M_w < 500 g/mol) polyethylene (paraffin) superimposed on a polystyrene spectrum, for example $C_7H_7^+$ and $C_9H_7^+$ in Fig. 2(bottom). Paraffin wax is an additive typically added in styrenic polymers to improve the processability[9].

A possible interpretation of the results in Fig. 2 is that paraffin is present at the surface of the high-flow grade mouldings. This can possibly be explained in terms of the lower surface energy and lower viscosity[10,11] of the paraffin than the entangled polystyrene matrix and to a flow-induced size separation effect.

CONCLUSIONS

This study indicates that during injection moulding of commercial polystyrenes, low-molar mass species (paraffin wax) present in the polymer matrix segregate towards the surface of the mouldings. TOF-SIMS can be a valuable tool for studying such effects.

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