The Development and Application of Shear Controlled Orientation Technology

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ABSTRACT

The application of specified macroscopic shears during the solidification of polymer melts provides a route for the development of preferred orientation of polymer molecules and reinforcing fibres in solid polymer and polymer matrix composite extrudate and mouldings. Shear Controlled orientation technology (SCORTEC) also provides a route for the elimination of internal weld lines, sinking and other processing defects.

The basic technology will be described with respect to microstructure control in moulding (SCORIM), in continuous extrusion (SCOREX), and a new method for the production of curvilinear extruded profile (SCORBEND).

One example of (SCORTEC) is described in more detail and is based on the production of defect-free mouldings in glass fibre reinforced polypropylene containing a thick section remote from the feed gate.

Key Words

extrusion, injection moulding, thermoplastics, shear, fibre orientation

INTRODUCTION

To apply macroscopic shears [1] to a solidifying melt within a cavity requires the provision of a multiplicity of live feeds to the cavity, where the pressure applied to each of the feeds can be independently controlled. Another requirement is to be able to displace sufficient molten material within the cavity to create a macroscopic shearing of the melt.

An embodiment of this concept [2] in the form of a two live-feed device is illustrated in Figure 1, located between the injection moulding machine screw/barrel and the mould cavity. Initially, the pistons A and B are positioned to allow the melt to enter the cavity from either one or both of the feeds. When the cavity is full, pistons A and B are moved back and forth to operate on the solidifying melt.

Pistons A and B may be moved back and forth at the same frequency with a phase difference of 180°, thereby applying a macroscopic

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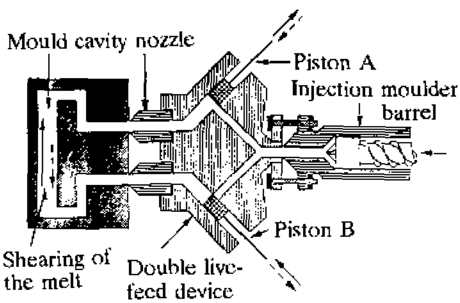

Fig.1. Schematic diagram of one embodiment of a two live-feed device [1,2].

shear at the melt-solid interface and inducing the preferred alignment of any alignable constituent at the melt-solid interface.

Pistons A and B may be moved back and forth at the same frequency and in phase, thereby applying alternately compression and decompression of the melt. This mode of operation causes shear heating in the narrow sections of cavities and runner systems, and provides for extended periods of maintenance of hold pressure and feeding of melt to the cavity to compensate for shrinkage.

Pistons A and B can be held forward to provide a static pressure as in conventional moulding.

The frequency and displacement of the pistons A and B and the sequencing of the three modes of piston movement are selected to optimize fibre orientation and moulding cycle time, whilst reducing or erasing moulding defects. Such defects include porosity and internal weld lines. SCORTEC has been developed for use in injection moulding, in continuous extrusion and the extrusion of curvilinear profile.

RESULTS AND DISCUSSION

Shear Controlled Orientation in Injection Moulding (SCORIM)

SCORIM offers the following benefits to the injection moulding process:

- management of fibres and molecular alignment to give enhanced stiffness and strength and control of thermal expansivity.
- in-situ formation and management of liquid crystal polymer fibres in a polymer matrix arising from the processing of a polymer blend.
- moulding to close tolerances.
- freedom from sink marks.
- elimination of internal weld lines to enhance physical properties and aesthetics of moulded parts.
- control of residual stresses, particularly in thicker section parts.

The pistons that provide for the generation of shear in the mould cavity may be configured to provide for alignment in more complex cavities [3,4], including the formation of laminated microstructures by design. SCORIM applies to thermoset matrix composites [5] and is equally effective when applied to semicrystalline polymers [6] and to thermotropic liquid crystal polymers, where substantial enhancement of stiffness and strength results from the application of specified macroscopic shears.

One example of the application of SCORIM to 30 weight per cent glass fibre reinforced polypropylene illustrates the power of the process for the elimination of porosity and the increase of strength in polymer matrix composite moulding. This example is illustrated by the reproduction of radiographs and data from the Ph.D thesis by A Zadhoush [7].

A change in moulded section thickness can have a marked effect on the mechanical performance of fibre reinforced plastics articles. SCORIM may result in substantial reductions in the detrimental effects of changes in moulded section thickness. Figure 2 (a) is a diagram of the mouldings made in which the test bar had a change of section from 10mm to 20mm at the centre (The dimensions are in mm). Figure 2 (b) shows a section which was cut from the centre of the test bar for CMR examination. Figures 3,4 and 5 respectively show contact micro radiographs of the section shown in Figure 2 (b) taken from moulding made conventionally, with in-phase, and with 180°

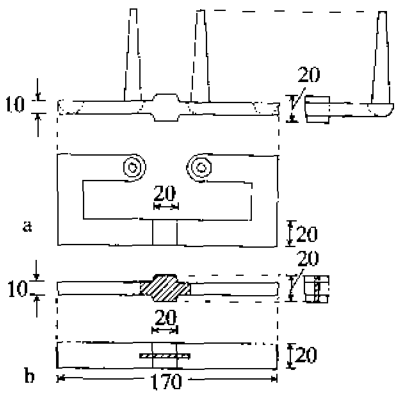

Fig.2(a). The mould geometry used to investigate the effect of change in section thickness [7].

Fig.2(b). The position of the sections taken for CMR studies.

out of phase operation of the packing pistons.

The use of the out of phase operation of the SCORIM process leads to a reduction in the quantity of transverse fibres present within the thicker section.

The use of in-phase or out of phase operation leads to the complete elimination of porosity present in mouldings produced by conventional injection moulding.

Tensile tests were made on the 20mm section machined to match the remaining 10mm

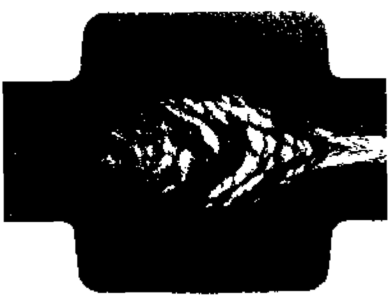

Fig.3. CMR of the section illustrated in Figure 2 (b) taken from a moulding produced by conventional injection moulding [7].

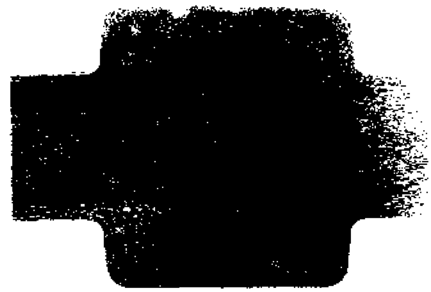

Fig.4. CMR of a section from a void-free moulding produced by in-phase operation of pistons A and B to provide for an oscillating hold pressure.

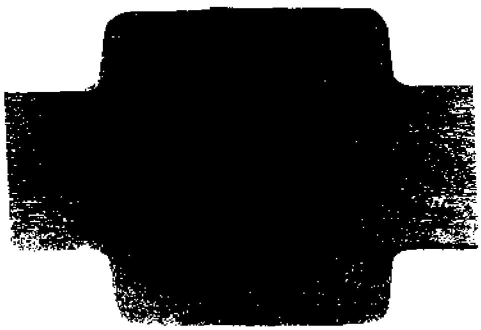

Fig.5. CMR of a section from a moulding produced by 180° out of phase operation of pistons A and B.

thick sections. The tensile strengths of bars produced by in-phase and out of phase operation of the packing pistons were 43 MPa and 61 MPa, respectively, reflecting the relative importance of a decrease in the extent of transversely oriented fibres to the elimination of porosity.

This example illustrates the role and effectiveness of SCORIM for the elimination of moulding defects and the management of fibre orientation in moulded components.

Shear Controlled Orientation in Extrusion (SCOREX)

SCOREX may be considered to be a continuous moulding process. The appropriate positioning of the pistons within the extrusion die, as illustrated

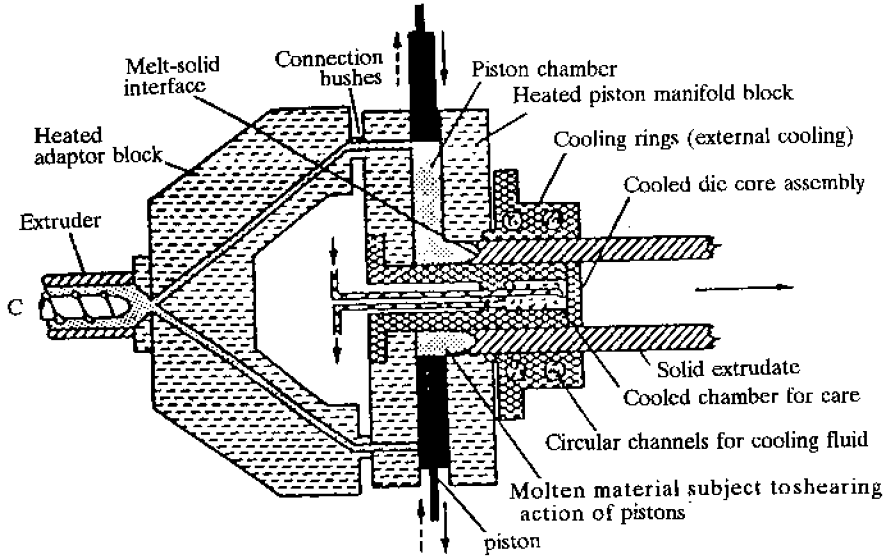

Fig.6(a). Schematic diagram of the centre section through the SCOREX die assembly used for the production of tubes [8]. On this tube die there are four pistons spaced at equal intervals, with two normal to the plane of the diagram, not shown. The appropriate sequencing of the operation of the pistons produces circumferential alignment of fibres and molecules.

in Figure 6 (a), then provides for control over the solidification process. This results in the control of the preferred orientation of reinforcing fibres [8], and also of molecular alignment, with the consequent enhancement of physical properties.

The application of macroscopic shear is at the melt-solid interface within the die body and this interface is positioned appropriately within the die by selective cooling of the polymer compound. The plastic emanates from the die as a solid and therefore the requirement for downstream sizing equipment is eliminated.

The overall benefits of the SCOREX process are:

- good dimension control.
- uniformity of microstructure, particularly with fibre reinforced plastics.
- enhanced molecular and/or fibre orientation transverse to the extrusion direction.

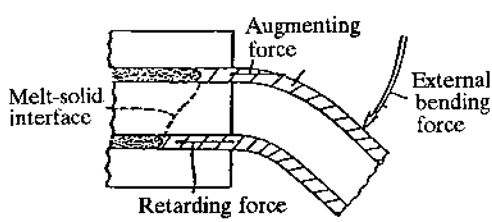

Fig.6(b). Schematic diagram of one arrangement for the production of curvilinear extrusions.

- control of residual stresses, stress-free thick sections can be produced.

Some examples of SCOREX dies with associated pistons positioned to induced transverse

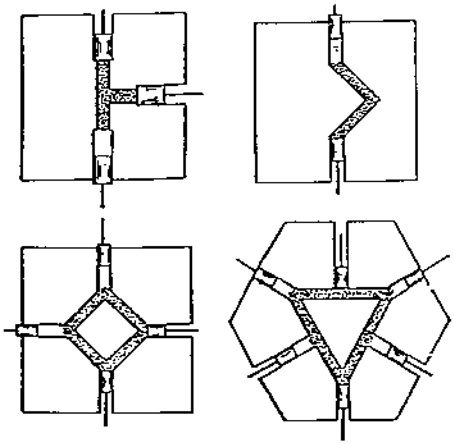

Fig.7. Illustrative example of SCOREX dies that provide for management of orientation in profile extrusion.

orientation in selected profiles are illustrated in Figure 7.

SCORBEND

SCORBEND is a development of the SCOREX processes which utilises in particular the solid product feature of that process.

The application of specifically directed forces to the extrudate leaving the die causes the extrudate to bend in specific directions. Provided that the position of the melt-solid interface is controlled and located within the die, then forcing the extrudate to one side simultaneously increases the material flow selectively to maintain a constant wall section. A schematic diagram of the apparatus is shown in Figure 6 (b) and some typical profiles are illustrated in Figure 8.

The benefits of the SCORBEND process over other more conventional methods of generating bends in parts by moulding or profile extrusion are:

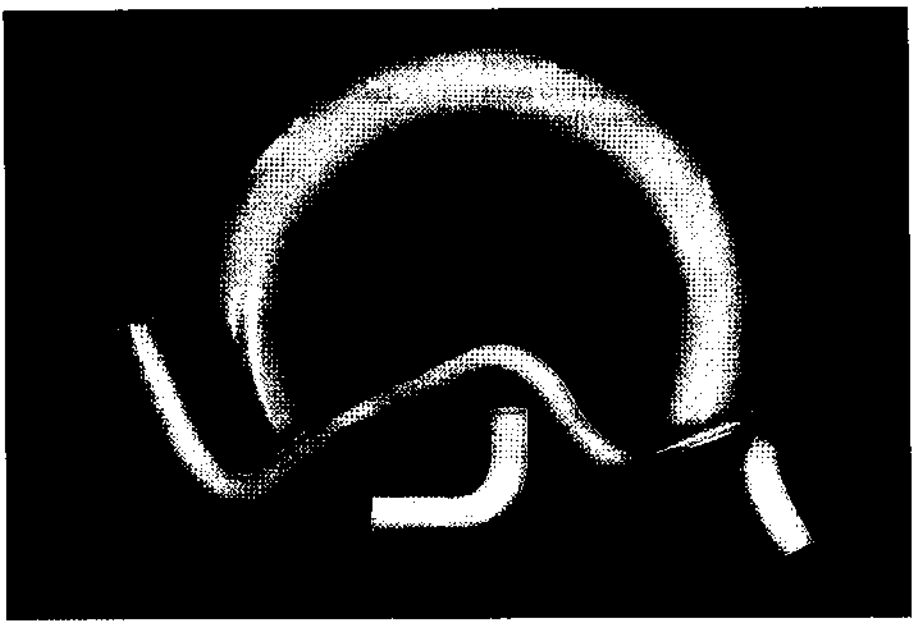

Fig.8. Some examples of pipe bends ranging from 63mm to 180mm diameter with excellent control of diameter and wall thickness, and illustrating the versatility of the SCORBEND process.

- uniformity of section thickness in all positions in the bend.
- uniformity of the cross-section of hollow products at all positions in bends.
- in principle can be scaled up to large sections- say one metre plus.
- any angle of bend can be programmed into the process without the need for additional tooling.
- complex 3-dimensional bend geometries can be produced.
- all the benefits of the microstructure and stress control of the SCOREX process can be obtained.

CONCLUSIONS

Shear controlled orientation technology provides a route for the control of the microstructure throughout the volume of a polymer or polymer matrix moulded or extruded product, with the consequential influence over physical properties. In essence it relates to the control of micro-structure and extrusion defects, and consequent enhancement and optimisation of physical properties where needed in a product to meet specified requirements. This is exemplified in the moulding of variable thickness mouldings in glass fibre reinforced polypropylene.

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