A study of the effect of injection speed on fibre orientation in simple mouldings of short glass fibre-filled polypropylene

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The pattern of fibre orientation in injection moulded strips of glass fibre reinforced polypropylene has been studied using the technique of contact micro-radiography. It has been found that the fibre orientation in the core of the mouldings is very dependent on injection speed. High injection speed gives alignment of fibres transverse to the flow direction, while for very low speeds the fibres align parallel to the flow. The associated changes in topography of the mouldings have been studied using scanning electron microscopy. The rheological properties of both glass fibre-filled and unfilled polypropylene have been studied in a capillary rheometer. At low shear rates, the fibres cause a significant increase in viscosity, but at the shear rates likely to be encountered in injection moulding, the filled and unfilled melts have very similar viscosities. The rheological data can be used to interpret the pattern of fibre orientation in the mouldings.

1. Introduction

Short glass fibre-reinforced thermoplastics (SFRTP) are an increasingly important class of engineering materials. Significant improvements in tensile strength and stiffness can be obtained relative to the matrix material, as well as a raising of the maximum working temperature.

The most widely used process for manufacturing articles from SFRTP is injection moulding. For a given unfilled thermoplastic the properties of the moulding depend on the particular morphology developed as a result of the processing conditions. In the case of fibre-filled thermoplastics the situation is more complicated in that the properties of the moulding will depend not only on the matrix properties, but also on the fibre concentration, fibre orientation and fibre length distribution.

If these materials are to be used efficiently in load-bearing engineering applications, it is desirable that the mechanical properties of a moulding, however complex, be predictable at the design stage. Although there are many theories for predicting the properties of a uniaxial long fibre composite, the problem becomes formidable in the case of practical mouldings in SFRTP due to the short length of the fibres and the complex pattern of orientation. At this stage, detailed studies are being conducted on simple geometry mouldings in an attempt to provide a basic foundation for the processing–property relationships in more complex mouldings.

Much experience has been gained with these materials by commercial moulders, and empirical procedures for obtaining good quality mouldings have been developed [1–5]. In addition, systematic research has been carried out showing the extent to which mechanical properties can be affected by processing conditions [6, 7]. During the moulding process the fibres may become oriented in a complex manner, often forming layers of differing orientation [8, 9]. This can produce marked anisotropy of mechanical properties [10]. It has been shown for short glass fibre-filled thermosetting materials

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that flow geometry has a major effect on fibre orientation [11, 12], and also that melt viscosity and shear rate can significantly alter the proportions of the oriented regions [11]. Orientation that is unfavourable with respect to the loads encountered in service can lead to component failure both in thermosetting and thermoplastic materials [13].

A considerable amount of attention has been devoted to the rheology of this class of materials [14–21] but only in a few cases have attempts been made to relate this to the behaviour of the material under commercial processing conditions [22–24].

The work presented in this paper is part of a programme aimed at predicting the pattern of fibre orientation in a simple moulding from a knowledge of the basic rheological properties of the material, the moulding conditions, and the mould geometry. The experimental approach in the main programme has been to study the fibre orientation of mouldings over a wide range of processing conditions, and to try to relate it to the flow behaviour during mould filling. This demands a knowledge of the flow properties in both simple and complex flows. In this paper only the effect of injection speed is investigated.

In our early studies of mould filling behaviour a striking change in the fibre orientation was observed at very low injection speeds. These were below the speeds normally employed in practice, but it was thought important to study this effect in detail because although the injection speeds were low, the levels of shear rate obtained will occur in practice when moulding articles containing thick cross-sections.

Injection speed also affects the surface finish of the moulding. In many applications a glossy finish is required, in which case a high injection speed is essential. The effects of injection speed on surface finish have been studied in addition to the effects on structure with a view to understanding the physical changes which give rise to a gloss or matt surface.

For a given mould geometry other factors may affect the orientation and length of fibres and this is the subject of a comprehensive set of experiments, now underway, covering the range of typical moulding conditions.

2. Experimental

2.1. Moulding equipment

The injection moulding machine used in this work was a BIPEL 130/25 model with a 130 tonf. (~ 1.3 MN) clamping force and 6.6 oz. (~ 187 g) maximum shot weight. A special feature of this machine was the closed loop control of the injection process using a Bosch SPR 200 adaptive control system. This allowed close control of the speed of injection and the pressure in the mould cavity through a servo-hydraulic value, and ensured good repeatability of mouldings from shot to shot.

The mould was a two cavity bar mould (Fig. 1) of dimensions 190 mm × 30 mm × 1.5 mm, with a semicircular gate of 1 mm radius. This was chosen to help develop an understanding of the flow behaviour in a simple geometry. One cavity was drilled to take a flush mounted pressure transducer which fed a signal back to the controller.

2.2. Moulding conditions

Mouldings were produced under three sets of conditions:

(1) Fast constant speed injection (injection time = 0.2 sec).

(2) Slow constant speed injection (injection time = 11 sec).

(3) Stepped injection, starting slowly and abruptly changing to fast after 50% of the shot had been injected.

Other machine conditions were:

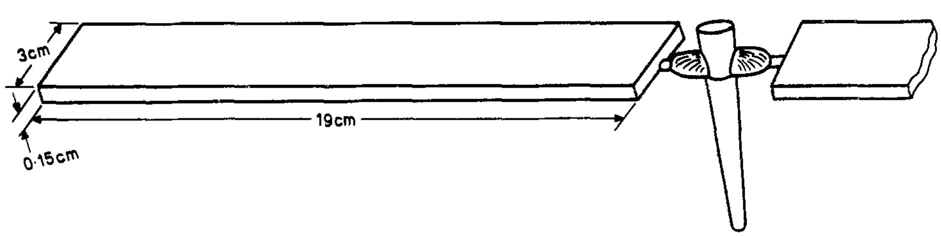

Figure 1 Simple strip moulding used for fibre orientation studies.