



**Evaluation of mould designs for preparing standard plate  
specimens of plastics by injection moulding.**

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## SUMMARY

The properties of the material in components prepared by injection moulding are anisotropic as a result of the alignment of molecules or fibres during melt flow. ISO test methods for the determination of the mechanical properties of plastics recommend or specify the use of the multipurpose test specimen described in ISO 3167. When prepared by injection moulding, this specimen will have molecular or fibre alignment predominantly along its length. Measured property values using this specimen will then refer to the likely upper bound for properties in injection moulding.

For purposes of materials selection and design, additional data are needed to indicate, as a minimum requirement, the lower bound to properties and, ideally, to show the dependence of properties upon direction for different levels of fibre or molecular orientation.

The availability of specimens in the form of a plate would enable the anisotropy of properties to be measured by testing specimens cut at different angles to the orientation direction. By standardising the geometry and dimensions of a standard mould and the processing conditions for specimen preparation, the data generated on these specimens will be traceable to well defined moulding and flow conditions. The work reported here has been concerned with defining a suitable geometry for such a mould. It is part of a much wider programme of research into the development of measurement methods for advanced materials funded by the Department of Trade and Industry.

The main requirements for the mould are that

- it should provide plate specimens whereby the anisotropy of a wide range of properties can be determined.

- a high, but realistic, level of fibre or molecular orientation is obtained so that upper and lower bounds for properties can be measured.
- the material structure in the central region of the moulded plates is homogeneous so that several test specimens with comparable properties can be cut from each plate.
- a wide range of filled and unfilled plastics can be moulded.

Based on studies carried out on an existing plate mould, a new mould has been designed and manufactured with the aim of optimising certain aspects of the mould design. The runner and gate regions can be removed so that the influence of different feed geometries and gate thicknesses can be investigated. Two novel runner geometries have been manufactured and used to mould plate specimens of two glass fibre filled thermoplastics, a glass fibre filled polypropylene (GFPP) and a glass fibre filled poly(butylene terephthalate) (GFPBT). Optical microscope observations and mechanical property measurements have been used to assess the fibre orientation in different regions of the plates.

The results of this work reported here demonstrate that one of the runner geometries is a preferred choice on which to base a standard for the preparation of plate specimens by injection moulding. However as part of the preparation of this standard, it would be desirable to establish the suitability of this mould design for a wider range of plastics materials.

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Approved on behalf of Managing Director, NPL  
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## 1 INTRODUCTION

One way for the plastics industry to improve performance/cost ratios is to predict more accurately the performance of components from materials properties data. A major limitation with design with plastics at present is a lack of data on the anisotropy of properties (1-3). A standard injection moulded test plate is required to facilitate the acquisition of these data. The orientation of fibres in injection moulded thermoplastics components is influenced by the flow behaviour of the melt in the sprue, runner and mould cavity, and processing conditions such as melt and mould temperature and flow rate (2-11). The control of fibre alignment in injection moulding is most clearly demonstrated by the use of live-feed injection moulding technology with which components with highly-aligned fibres can be produced (12-13).

One of the projects funded at the National Physical Laboratory (NPL) by the DTI programme on Measurement Technology and Standards has been concerned with the development of a standard for preparing a multipurpose test specimen, in the shape of a plate, by injection moulding.

A desired specification for the injection moulded plate can be summarised as:

- \* a plate size of at least 150 mm x 150 mm, thus allowing multipurpose test specimens to be cut both parallel and perpendicular to the flow direction;
- \* a specimen that has the maximum anisotropy to be expected in an injection moulded component, thus yielding likely upper and lower bounds for property data;
- \* and possibly, with options on gating geometry and plate thickness to allow for use of the tool with unfilled, particle-filled and fibre-filled materials.

The live-feed technology described above and in references 12 and 13 was not considered to be suitable for use in a standard due to its current limited availability. In order to aid the development of a standard plate mould, studies were initially carried out on specimens prepared using an existing plate mould, referred to as the ERA-Brunel plate. Following evaluation of that mould tool (14-16) and consultation with experts in the UK and BASF (Germany), two designs for the feed system of a new plate mould (150 x 150 mm) were developed. These designs were based on the principal of equal flow lengths from the sprue to the leading edge of the gate. Design 1 has the out-of-plane region required to balance the flow lengths in the diverging section of the feed system. Design 2 has the out-of-plane region following the diverging section and immediately preceding the edge gate to the plate cavity.

A mould tool was subsequently made, using inserts to enable changes of the feed systems to be made. Moulding trials were carried out using the tool with both feed designs for glass fibre reinforced polypropylene (GFPP) and poly(butylene terephthalate) (GFPBT) materials.

Moulding trials were also carried out using a multipurpose test piece mould (17, 18). Testing of these specimens provided a reference for comparison with mechanical properties data obtained for specimens cut parallel to the flow direction from the plate mouldings.

The mouldings produced using the two new feed designs and the multipurpose test specimens were tested to determine modulus and stress and strain to failure and examined to determine the level and distribution of fibre orientation at various positions across and through the thickness of the plates.

## 2 MATERIALS

Four materials were investigated in this and the previous work using the ERA-Brunel mould. Two grades of polypropylene (PP) were used: an unfilled polypropylene reference T30S and a glass fibre filled polypropylene reference PC072/3 NAT. These materials were supplied by Montell UK Ltd. Also, two grades of poly(butylene terephthalate) (PBT) were used: an unfilled grade reference Ultradur B4500 and a glass fibre filled grade reference Ultradur B4300G4. The PBT materials were supplied by BASF plc. Details of these grades are given in Table 1. The dimensions of the fibres, measured optically after burning off the resin, are given in Table 2.

**Table 1 Materials description**

| Material | Description                                     | Supplier and Grade reference | % weight glass fibres | % volume glass fibres | NPL material reference |
|----------|-------------------------------------------------|------------------------------|-----------------------|-----------------------|------------------------|
| PP       | Unfilled polypropylene                          | Himont (UK) Ltd T30S         | -                     | -                     | MAA000                 |
| GFPP     | Glass fibre filled polypropylene                | Himont (UK) Ltd PC072/3 NAT  | 30                    | 13.2                  | MAB000                 |
| PBT      | Unfilled poly(butylene terephthalate)           | BASF Ultradur B4500          | -                     | -                     | MAC000<br>MAE000       |
| GFPBT    | Glass fibre filled poly(butylene terephthalate) | BASF Ultradur B4300G4        | 20                    | 10.8                  | MAD000<br>MAF000       |

**Table 2 Measured dimensions of the glass fibres in the filled GFPBT and GFPP grades**

| Material | Fibre length, L ( $\mu\text{m}$ ) |                    | Fibre diameter, D ( $\mu\text{m}$ ) |                    | Aspect ratio L/D |
|----------|-----------------------------------|--------------------|-------------------------------------|--------------------|------------------|
|          | Mean                              | Standard deviation | Mean                                | Standard deviation |                  |
| GFPP     | 480                               | 127                | 12.5                                | 1.0                | 38               |
| GFPBT    | 334                               | 98                 | 9.0                                 | 1.0                | 37               |

## 3 MOULDINGS

### 3.1 PLATE MOULDING GEOMETRIES

#### 3.1.1 Description of the ERA-Brunel plate geometry

A plate mould, developed in an earlier project, was used in previous work (14-16) to produce plates that were 150 mm x 150 mm in size. Plan and cross-sectional views of the of the plate geometry moulding are shown in Figure 1. Plates of thickness 2.65 mm and 4 mm were moulded by the use of inserts. The plate was fed by a coathanger edge gate. The thickness of the gate varied in proportion to the thickness of the plate and was 1.5 mm and 2 mm for plate

thicknesses of 2.65 mm and 4 mm respectively. All other dimensions of the cavity were independent of the plate and gate thicknesses.

### 3.1.2 Description of the NPL plate geometry 1

The plate and feed system of the NPL plate design 1, excluding the sprue, is shown in Figure 2. The sprue was perpendicular to the plane of the plate and joined at the apex of the feed system. The design was based on the principal of equal flow lengths from the sprue to any point along the edge gate. In this design the out-of-plane region required to balance the flow lengths was in the diverging section of the feed system. Due to the versatility required for this mould the tool was made up comprising of separate inserts for the runner, gate and plate. This permitted the use of plates of 2 mm or 4 mm thickness and gates of 1 mm or 2 mm thickness and 5 mm in length. A plate thickness of 2 mm and a gate thickness of 1 mm and 2 mm were used in the moulding trials reported here.

### 3.1.3 Description of the NPL plate geometry 2

The NPL plate geometry design 2 differed from that of design 1 only in terms of the shape of the feed system. The plate and feed system of the NPL plate design 2, excluding the sprue, is shown in Figure 3. Again, the design was based on the principal of equal flow lengths from the sprue to any point along the edge gate. However, in this design the out-of-plane region required to balance the flow lengths was located after the diverging section of the feed system and immediately preceding the edge gate to the plate cavity. A plate thickness of 2 mm and a gate thickness of 1 mm were used in the moulding trials reported here.

The plate mouldings produced using designs 1 and 2 were 150 mm in length and 150 mm in width.

## 3.2 MULTIPURPOSE TEST SPECIMEN MOULDING GEOMETRY

Multipurpose specimens were made using the ERA-Brunel tool that has an insert for moulding a specimen with dimensions in accordance with the multipurpose test specimen type ISO 527-2/1B (17, 18).

## 3.3 MOULDING TRIALS

Details of the ERA-Brunel moulding trials are reported in detail elsewhere (15). Details of the moulding trials using the NPL plate mould designs 1 and 2 are presented in Appendix 1, and of the multipurpose specimen moulding trials in Appendix 2.

The consistency of the mouldings produced in the trials was assessed using the injection time and  $P_{int}$  values, both obtained from the output console of the injection moulding machine and also by weighing the mouldings with the feed system, runner and gate still attached. The  $P_{int}$  value is the integral of the pressure measured by a transducer located below a cavity ejector pin, integrated with respect to time between two selected times during the injection cycle. Mouldings for subsequent testing were chosen on the basis of their consistency as indicated using these measures.

## 4 FILLING PATTERNS IN THE PLATE MOULDS

### 4.1 ERA-BRUNEL PLATE GEOMETRY

Short-shot moulding trials were used to reveal the filling patterns for GFPBT and GFPP using the ERA-Brunel mould geometry, Figures 4 - 7. The observed short-shot filling patterns were similar for injection times of approximately 1 and 4 seconds and for both the filled and unfilled grades of each material.

For both the fibre-filled and unfilled PP materials under all processing conditions the mould cavity filled with a relatively flat flow front in the plate region of the cavity, Figures 5 and 6. However, for the PBT materials under all processing conditions the filling behaviour was quite different, Figures 4 and 7. The severity of the flow advancement along the edges (preferential filling) was such that a knitline was formed at the far end of the moulding opposite to the gate. The knitline was visible in some of the mouldings and was approximately 10 mm long, extending from the edge of the plate towards the gate. The validity of short-shot mouldings as a "snap-shot" of the filling process is itself questionable. However, the GFPBT mouldings clearly exhibited a knitline, as was evident by burning of material in that region. Due to this filling behaviour the validity of taking samples from these plates is perhaps questionable. However, the central region of these plates had a reasonably flat flow front and could perhaps be successfully used for samples in preference to the use of specimens cut from regions near the sides of the plate. Furthermore, due to the practicality of gripping samples in mechanical testing the region near the edge of the plate is not suitable for determining anisotropy of properties.

Results of investigations into the filling behaviour and fibre orientation in the ERA-Brunel plate moulding and the comparison of predictions with experiments are presented in detail in references 15 and 16.

### 4.2 NPL PLATE GEOMETRY 1

The short-shot filling patterns for GFPP and GFPBT for mould design 1 are shown in Figures 8 - 10. The GFPP material filled relatively uniformly across the width of the plate, Figure 8, but again the GFPBT material filled preferentially along the edges of the plate, Figures 9 and 10. The filling for GFPBT was perhaps marginally better than when using the ERA-Brunel mould, particularly when using the 2 mm thick gate. The use of the thinner gate, 1 mm compared with 2 mm, appeared to cause the melt front region that reached the gate first (ie at the centre of the gate width) to hesitate more significantly, presumably due to increased flow resistance arising from the contraction in the flow path cross sectional area, Figure 9 cf 10. The resultant effect was that the melt in the central gate region cooled thereby increasing further the resistance to flow. As a consequence, material flowing nearer the edges of the plate overtook that in the centre to produce the preferential filling along the edge. In this respect the filling behaviour was sensitive to the gate geometry. The flow was thus unstable in that there was an element of positive feedback in the filling behaviour where a slight hesitation in flow resulted in increased flow elsewhere. It is noted that these trials were carried out near the limit of processability of these materials for this plate mould. The combination of the long length of the plate, its thinness (2 mm) and the fact that PBT has a relatively sharp melt transition resulted in excessive cooling and solidification of the melt in the cavity causing an increase in the required filling pressure. This set of conditions would, however, result in high shearing stresses being generated in the melt during filling of the cavity that might produce the high anisotropy that was being sought.

### 4.3 NPL PLATE GEOMETRY 2

The filling behaviour for the mould design 2 was qualitatively similar to that for the ERA-Brunel mould in that the GFPP filled the plate with a relatively uniform flow front and the GFPBT preferentially filled the plate along the sides of the cavity, Figures 11 and 12. However, in the case of GFPBT the preferential filling was more exaggerated than for either the ERA-Brunel mould or the mould design 1, Figure 12 c.f. Figures 7, 9 and 10.

## 5 OPTICAL MICROSCOPE OBSERVATIONS OF FIBRE ORIENTATION

Polished sections cut from the plate mouldings were observed using an optical microscope to gain information on any variation in fibre orientation through the thickness of the plate mouldings. No attempt has been made to determine orientation functions from image analysis of the geometry of fibre sections.

Observations were similar to those obtained for plate specimens prepared using the earlier mould and reported in reference (14) and revealed a layered structure (1,2,8,10). They indicate that

- there was a core region, approximately 0.4 mm thick in the GFPP mouldings in which the fibre orientation was predominantly at right angles to the flow direction.
- there was no evident core region of transverse orientation in the GFPBT plates, but the level of fibre orientation appeared less than that achieved in the GFPP mouldings in the regions near the surfaces. This conclusion is drawn from observations of orthogonal sections where highly oriented fibres were not apparent in the GFPBT specimens.
- no differences were apparent between mouldings prepared with the two runner geometries and the two gate thicknesses.

## 6 MECHANICAL PROPERTY MEASUREMENTS

Tensile specimens with the multipurpose test specimen geometry were machined from the GFPP and GFPBT plate mouldings at the locations shown in Figure 13. Measurements of the tensile stress/strain curve to failure were made on each of these specimens under a constant cross-head speed of 5 mm/min (approximate strain rate of 5% per minute). Prior to these tests, Young's modulus values were determined under a constant cross-head speed of 1 mm/min. For all of these measurements, at least 4 specimens were tested.

### 6.1 IN-PLANE HOMOGENEITY

For each of the materials, Young's modulus values obtained for specimens taken from different mouldings and locations, but of the same orientation, within the mouldings were reproducible to better than 2% of the mean value and generally better than 1%.

Values for the stress and strain at break were also highly reproducible. Values for stress at break were typically reproducible to within 2% of the mean and, for strain at break, within 5%. Comparison of these mean values obtained for specimens cut from the two locations in each plate revealed that there was no significant difference between properties at these locations, Figure 13. This indicates that a region that was at least 60 mm square existed in the centre of each moulding in which the structure was highly uniform.

## 6.2 COMPARISON OF FEED SYSTEM GEOMETRIES

Tables 3 and 4 list tensile properties obtained from plates moulded using the two new runner geometries described in section 3.1. Longitudinal and transverse refers to specimens cut with their long axis aligned along and perpendicular, respectively, to the direction of melt flow into the plate cavity.

The values recorded are averages obtained for specimens from the two locations in each plate. Also shown are values for the multipurpose specimen.

**Table 3 Comparison of properties of GFPP plates prepared using feed system designs 1 and 2 (see Figures 2 and 3).**

Gate thickness = 1 mm.

Values in brackets give percentage of value of the multipurpose specimen.

| PROPERTY                                            | DESIGN 1      | DESIGN 2      | MULTIPURPOSE SPECIMEN |
|-----------------------------------------------------|---------------|---------------|-----------------------|
| Longitudinal modulus (GPa)                          | 5.46<br>(76%) | 6.22<br>(87%) | 7.15                  |
| Transverse modulus (GPa)                            | 3.57          | 3.35          | -                     |
| Ratio of longitudinal to transverse modulus         | 1.53          | 1.86          | -                     |
| Longitudinal breaking stress (MPa)                  | 66.4<br>(79%) | 73.5<br>(87%) | 84.2                  |
| Transverse breaking stress (MPa)                    | 45.4          | 39.3          | -                     |
| Ratio of longitudinal to transverse breaking stress | 1.46          | 1.87          | -                     |

**Table 4 Comparison of properties of GFPBT plates prepared using feed system designs 1 and 2 (see Figures 2 and 3).**

Gate thickness = 1 mm.

Values in brackets give percentage of value of the multipurpose specimen.

| PROPERTY                                            | DESIGN 1       | DESIGN 2       | MULTIPURPOSE SPECIMEN |
|-----------------------------------------------------|----------------|----------------|-----------------------|
| Longitudinal modulus (GPa)                          | 6.79<br>(94%)  | 6.52<br>(91%)  | 7.20                  |
| Transverse modulus (GPa)                            | 4.08           | 3.76           | -                     |
| Ratio of longitudinal to transverse modulus         | 1.66           | 1.73           | -                     |
| Longitudinal breaking stress (MPa)                  | 107.5<br>(94%) | 105.0<br>(92%) | 114.0                 |
| Transverse breaking stress (MPa)                    | 64.8           | 62.8           | -                     |
| Ratio of longitudinal to transverse breaking stress | 1.66           | 1.67           | -                     |

Reference to Table 3 indicates that for fibre filled polypropylene, a higher degree of anisotropy was achieved with the runner system design 2 than with design 1. Longitudinal property values were approximately 85% higher than transverse values in design 2 but only 45 - 55% higher in design 1. This is also implied by a higher longitudinal modulus and longitudinal breaking stress, and a lower transverse modulus and transverse breaking stress for the runner design 2. However, the trend is less clear for the fibre filled PBT case in which the levels of anisotropy were similar for both designs, Table 4. The longitudinal property values were 65 - 75% higher than transverse values, but were perhaps slightly higher for design 2. For GFPBT the transverse modulus and transverse breaking stress were lower for specimens prepared using design 2 (as was the case for GFPP) but the longitudinal modulus was higher for design 1. There thus appears to be an inconsistency between these measurements that is not clarified by the breaking stress values that were essentially the same for both designs. A possible explanation relates to differences in degradation of the glass fibre reinforcement of the two materials during moulding of plates using the two feed designs (2, 4, 19, 20), for example excessive degradation of the fibre reinforcement of GFPBT in filling mould design 2 would predominantly have reduced the magnitude of the longitudinal properties rather than the transverse properties. Nevertheless, it appears that there was not a significant difference in the level of anisotropy obtained for GFPBT in using designs 1 or 2. The more significant observation, related to establishing a standardised mould design, is that the trends in anisotropy for each geometry varied significantly with material. For GFPP there was a significant difference in the level of anisotropy between geometries which was not observed for GFPBT.

A measure of the fibre orientation in the GFPP and GFPBT materials can be derived from the ratio of the longitudinal modulus of the plate to the modulus value for the multipurpose test specimen, and similarly for the breaking stress. Examination of the data, Tables 3 and 4, indicates that for GFPP the longitudinal values of modulus and breaking stress were in the range 76 - 87% (average 82%) of the values obtained using the multipurpose specimen. For GFPBT the range of 91 - 94% (average 92%) was significantly higher although the ratio of longitudinal to transverse property values was less than that for GFPP for mould design 2. This perhaps indicates that either the level of fibre orientation obtained in the GFPBT multipurpose test specimens was lower than that for the GFPP, or that fibre degradation was more significant or both.

### 6.3 INFLUENCE OF GATE THICKNESS

It was explained in section 3.1 that inserts were incorporated into the new mould to enable the influence of gate thickness on plate properties to be investigated. Plates of fibre filled PBT material were moulded using the feed system design 1 with gate thicknesses of 1 mm and 2 mm, the latter corresponding to no change in mould thickness at the gate (ie 2 mm thick plate). Values for tensile properties of specimens cut from these plates are compared in Table 5. The results imply that a higher level of fibre orientation was achieved with the 1 mm thick gate, although the transverse modulus values are not consistent with this. The property values recorded for the 1 mm gate thickness in Table 5 are the same as those listed in Table 4 for the feed system design 1. There were some inconsistencies in these values when compared with data in Table 4 for material moulded using the feed system design 2. Despite these uncertainties, it is probably fair to conclude that for fibre filled PBT, marginally higher levels of fibre orientation were achieved with a 1 mm thick gate than when a 2 mm gate was used.

**Table 5** Comparison of properties of GFPBT plates prepared with gate thicknesses of 1 mm and 2 mm and mould design 1

Values in brackets give percentage of value of the multipurpose specimen.

| PROPERTY                           | GATE THICKNESS |               |
|------------------------------------|----------------|---------------|
|                                    | 1 mm           | 2 mm          |
| Longitudinal modulus (GPa)         | 6.79<br>(94%)  | 6.30<br>(88%) |
| Transverse modulus (GPa)           | 4.08           | 4.05          |
| Longitudinal breaking stress (MPa) | 107.5          | 102           |
| Transverse breaking stress (MPa)   | 64.8<br>(94%)  | 66.6<br>(89%) |

## 7 DISCUSSION

The moulding trials clearly demonstrated that there were significant differences in the flow behaviour of the two materials within each of the plate mould cavities. For all the geometries evaluated the GFPP material exhibited a relatively flat flow front across the width of the plate. However, the GFPBT material exhibited significant flow advancement along the sides of the plate that resulted in the formation of a knitline at the far end of the moulding from the gate. The flow advancement was greatest for mould design 2. The use of design 1 resulted in similar or possibly slightly better filling profiles than were obtained using the ERA/Brunel coathanger feed mould that was used in the previous work.

Despite these non-uniform filling profiles the reproducibility of properties measured within a central area 60 mm by 60 mm was good, indicating that flow advancement along the edges had little effect on properties in the central region. The reproducibility of properties was better than that obtained using the ERA-Brunel mould. The optical microscopy revealed differences in the fibre orientation structure between the materials but not between the mould 1 and 2 geometries.

The significant variation in the level of anisotropy of properties due to the design for GFPP but not for GFPBT makes the specification of a standardised mould geometry more problematic: the choice of geometry is material dependent. For the two materials investigated here, design 2 is favoured in that it yielded, on average, the highest levels of modulus and breaking stress relative to the multipurpose test specimen values. However, for GFPBT it did not yield the highest values of longitudinal modulus and breaking stress, although the difference in values between the geometries was small. A further unexpected result was that the highest level of anisotropy (GFPP with design 2) did not generate the highest values of properties relative to that obtained using the multipurpose specimen (GFPBT with design 1). This may have been due to differences in the level of fibre orientation and/or degradation of the two materials in the multipurpose test specimen.

## 8 CONCLUSIONS

The following conclusions summarize the important considerations and the potential to be expected from a standard plate specimen for obtaining upper and lower bound values of properties in injection mouldings.

- The new runner designs 1 and 2 give broadly comparable levels of anisotropy of properties to the earlier runner design but achieve better uniformity of properties over the central region of the moulding. The reproducibility of measurements of modulus and breaking stress in this region was typically better than 2% of mean values using the new mould designs.
- Values of longitudinal properties obtained for GFPBT using either design were closer to values obtained using the multipurpose test specimen (MPTS) than for GFPP. For GFPBT the longitudinal properties values obtained using the plate specimen were on average 92% of that of the MPTS values, and for GFPP they were 82%.
- Modulus and breaking stress values along the flow direction were 50 - 90 % higher than values transverse to the flow direction for the two designs for GFPP and GFPBT. For GFPBT, the level of anisotropy in these properties was similar for the two runner designs but, for GFPP runner design 2 achieved a small but significantly higher anisotropy than runner design 1.
- This result implies that design 2 would be the preferred mould design on which to base a standard for preparing standard multipurpose plate specimens. As part of the preparation of this standard, it would be desirable to investigate the suitability of this mould design for a wider range of materials.

## 9 ACKNOWLEDGEMENTS

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# APPENDIX 1: DESCRIPTION OF THE PLATE SPECIMEN MOULDING TRIALS USING NEW FEED DESIGNS 1 AND 2

MOULDING TRIALS: Wolfson Centre, Brunel University.

MOULD: NPL mould with nominally cavity thickness of 2.00 mm, gate thickness either 1 or 2 mm and with feed systems designated NPL design 1 or NPL design 2.

MACHINE: DEMAG D 150 NCIII - K, no 816 0802.

MATERIALS: MAB000: Himont glass fibre filled PP, ref PC072/3 NAT.  
MAF000: BASF glass fibre filled PBT, ref Ultradur B4300G4.

## NPL plate geometry 1 and 2 moulding trial results.

| Material                        | Material reference | Mould design: 1 or 2 | Gate thickness (mm) | Moulding reference nos.       | Injection time (s) <sup>*1</sup> | Moulding weight (g) <sup>*1</sup> | Melt temp (°C) | Mould temp (°C) |
|---------------------------------|--------------------|----------------------|---------------------|-------------------------------|----------------------------------|-----------------------------------|----------------|-----------------|
| PP with glass fibres (PC072/3)  | MAB000             | 1                    | 1                   | MAB610 - MAB634               | 1.26 - 1.28                      | 92.8 - 93.4                       | 249            | 60              |
| PBT with glass fibres (B4300G4) | MAF000             | 1                    | 1                   | MAF617 - MAF627 <sup>*2</sup> | 2.08 - 2.13                      | 127.6 - 128.2                     | 277            | 60              |
| PBT with glass fibres (B4300G4) | MAF000             | 1                    | 2                   | MAF720 - MAF740 <sup>*3</sup> | 2.09 - 2.11                      | 124.1 - 124.9                     | 276            | 59              |
| PP with glass fibres (PC072/3)  | MAB000             | 2                    | 1                   | MAB515 - MAB547               | 1.68 - 1.70                      | 126.0 - 126.7                     | 251            | 59              |
| PBT with glass fibres (B4300G4) | MAF000             | 2                    | 1                   | MAF530 - MAF548 <sup>*4</sup> | 2.60 - 2.86                      | 165.8 - 167.0                     | 269            | 58              |

### NOTES:

- \*1: Range valid for samples selected for subsequent testing.
- \*2: Samples obtained at shortest possible injection time, limited by machine capability. Higher melt and mould temperatures used cf MAF500 series.
- \*3: Moulding conditions set to match MAF600 series.
- \*4: Samples obtained at shortest possible injection time, limited by machine capability.

### ADDITIONAL NOTES ON RESULTS:

1. Injection time values obtained from print-out of injection moulding machine.
2. The weight referred to in the results is that of the plate specimen including the sprue and runner.



## APPENDIX 2: DESCRIPTION OF THE MULTIPURPOSE TEST SPECIMEN MOULDING TRIALS

MOULDING TRIALS: Wolfson Centre, Brunel University.

MOULD: ERA/Brunel MPTS mould with nominally cavity thickness of 4.00 mm, tool no. 1600.

MACHINE: DEMAG D 150 NCIII - K, no 816 0802.

MATERIALS AND SET MELT/MOULD PROCESSING TEMPERATURES:

MAB000: Himont glass fibre filled PP, ref PC072/3 NAT. 250 °C/60 °C

MAE000: BASF unfilled PBT, ref Ultradur B4500. 270 °C/58 °C

MOULDING TRIALS RESULTS:

| Material                        | Material reference | Moulding reference nos. | Injection time (s) | Moulding weight (g) |
|---------------------------------|--------------------|-------------------------|--------------------|---------------------|
| PP with glass fibres (PC072/3)  | MAB000             | MABY01-22               | 0.48 - 0.51        | 13.0                |
| PP with glass fibres (PC072/3)  | MAB000             | MABZ01-21               | 1.98 - 2.02        | 13.1                |
| PBT with glass fibres (B4300G4) | MAF000             | MAFY03-20               | 0.49 - 0.50        | 16.3 - 16.4         |
| PBT with glass fibres (B4300G4) | MAF000             | MAFZ01-22               | 1.91 - 2.06        | 16.3 - 16.4         |

NOTES ON THE RESULTS:

1. Injection time values obtained from print-out of injection moulding machine.
2. The weight referred to in the results is that of the plate specimen including the sprue and runner.



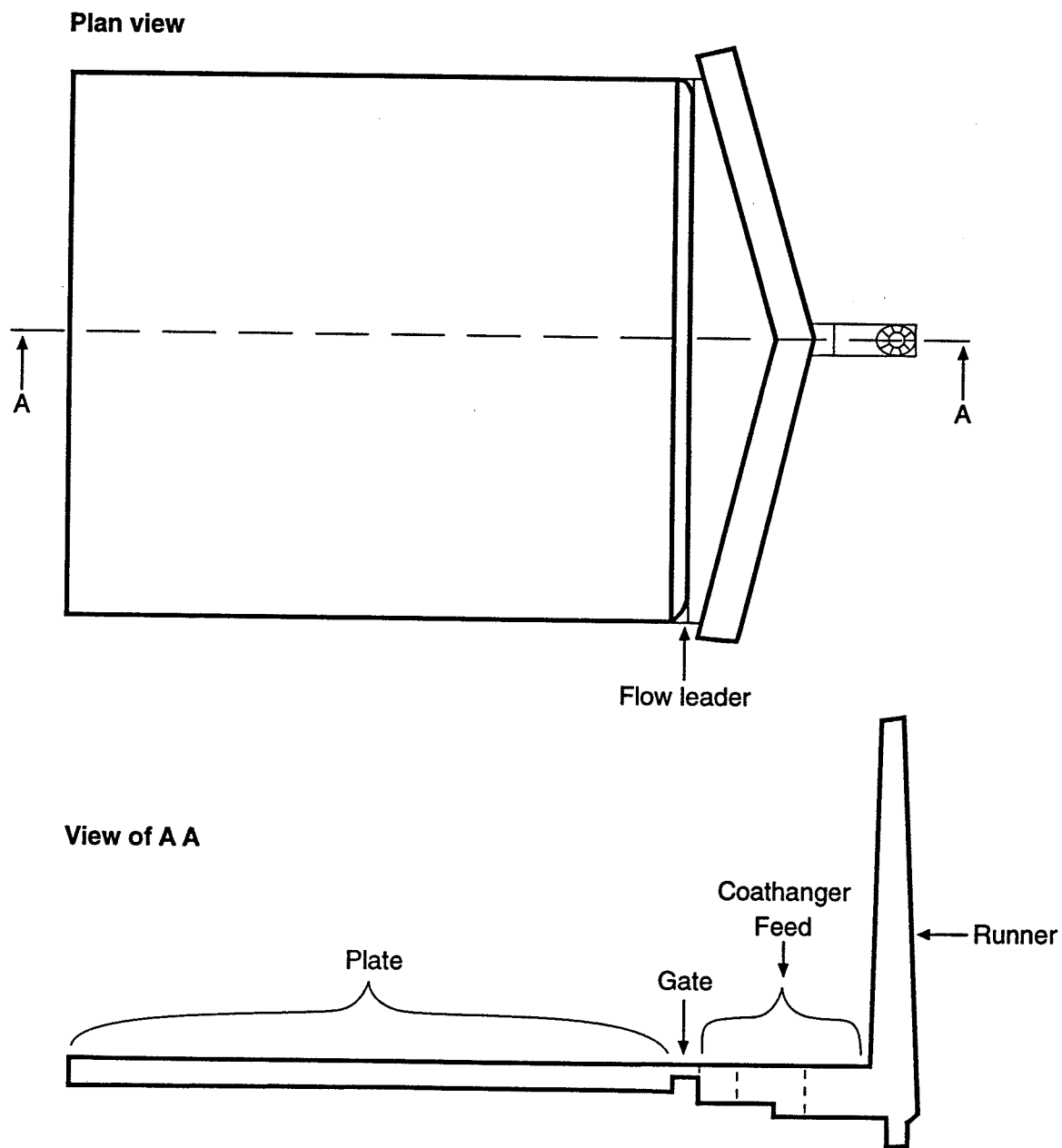


Figure 1 ERA-Brunel plate geometry plan and cross-sectional view showing coathanger feed system.

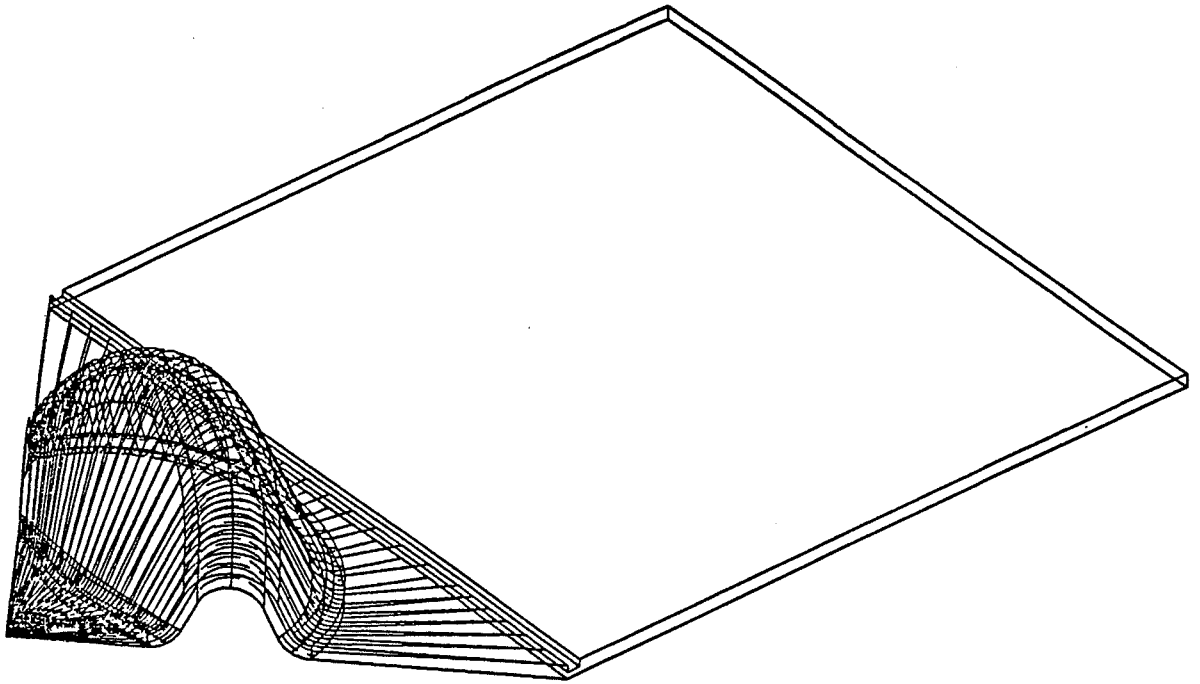


Figure 2 Feed system design 1, excluding sprue.

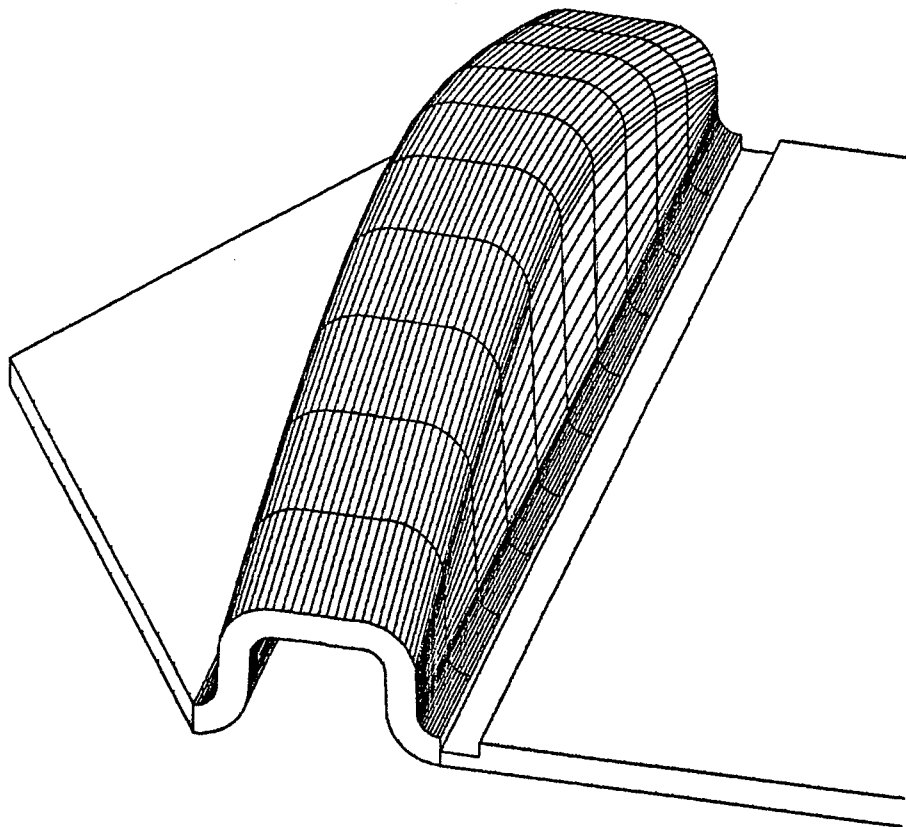


Figure 3 Feed system design 2, excluding sprue.

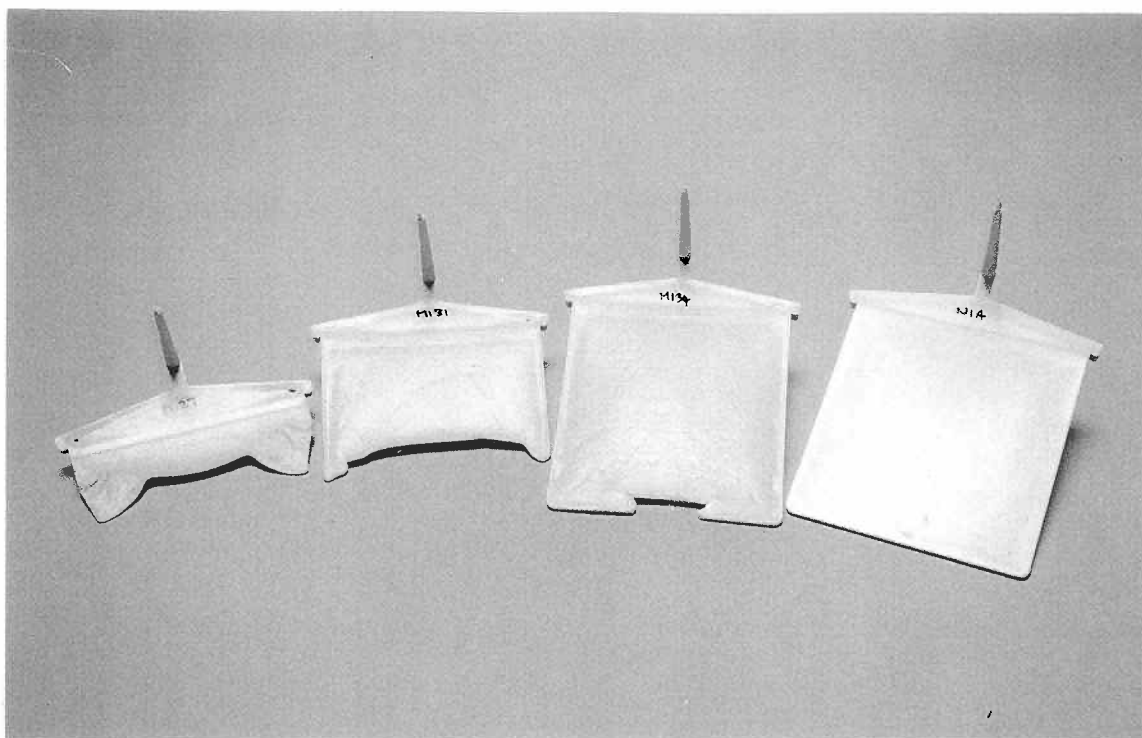


Figure 4 Typical short-shot and complete-fill plate mouldings of GFPBT.

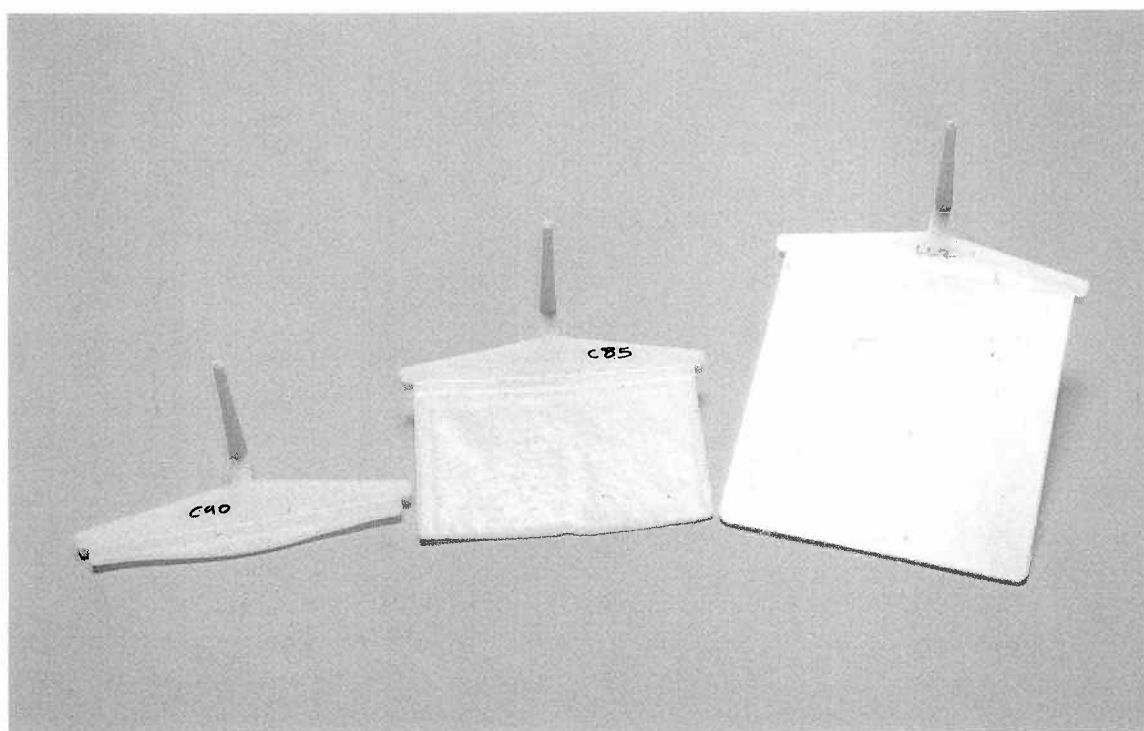


Figure 5 Typical short-shot and complete-fill plate mouldings of GFPP.

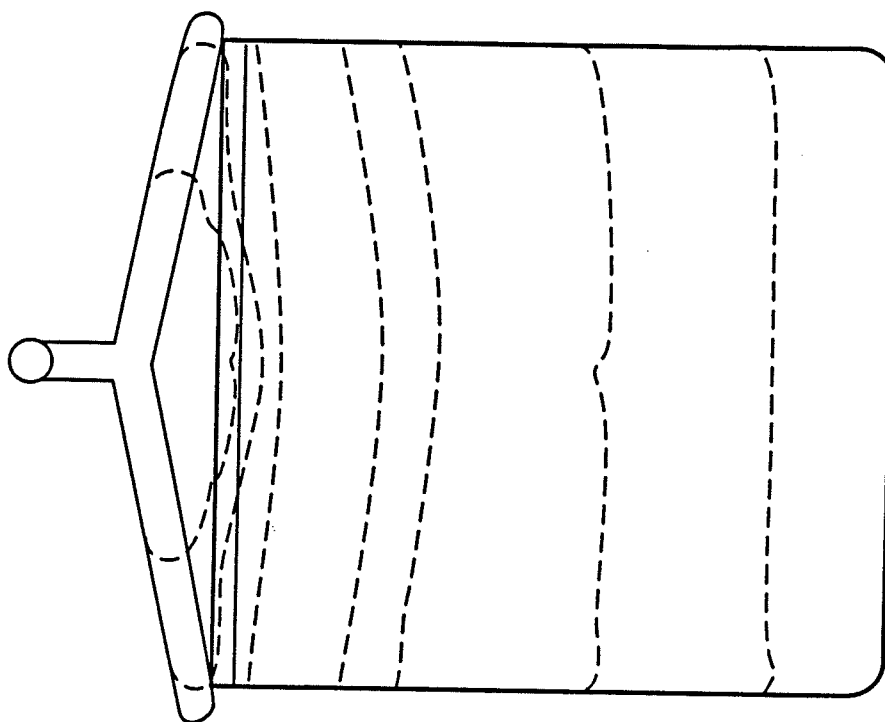


Figure 6 Short-shot filling profiles for GFPP, injection time 1 s, obtained using the ERA/Brunel plate mould.

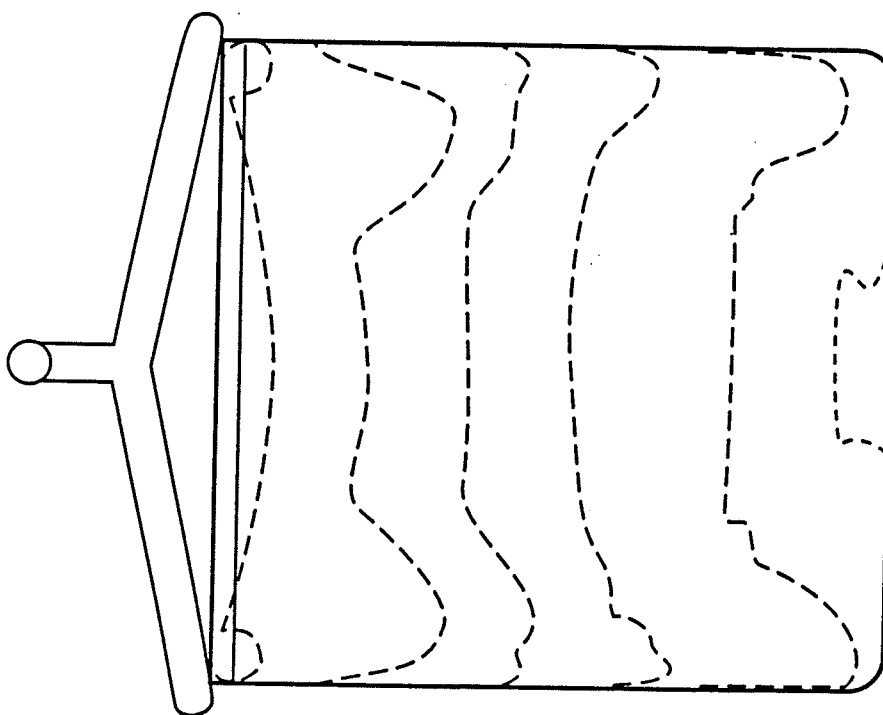


Figure 7 Short-shot filling profiles for GFPBT, injection time 1.5 s, obtained using the ERA/Brunel plate mould. Solid line defines cavity, broken lines define flow front of short-shot mouldings.

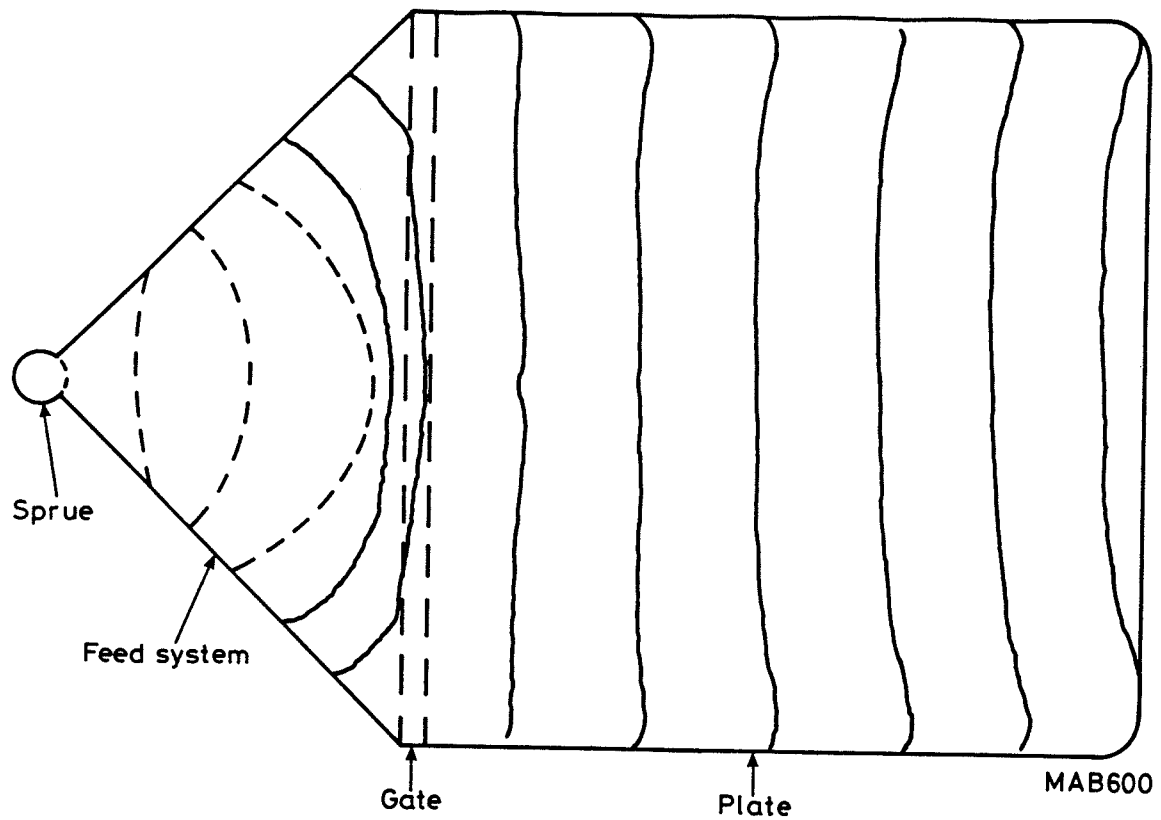


Figure 8 Short-shot filling profiles obtained using feed design 1, 1 mm thick gate, 2 mm thick plate for GFP. Mould trial reference: MAB600 series.

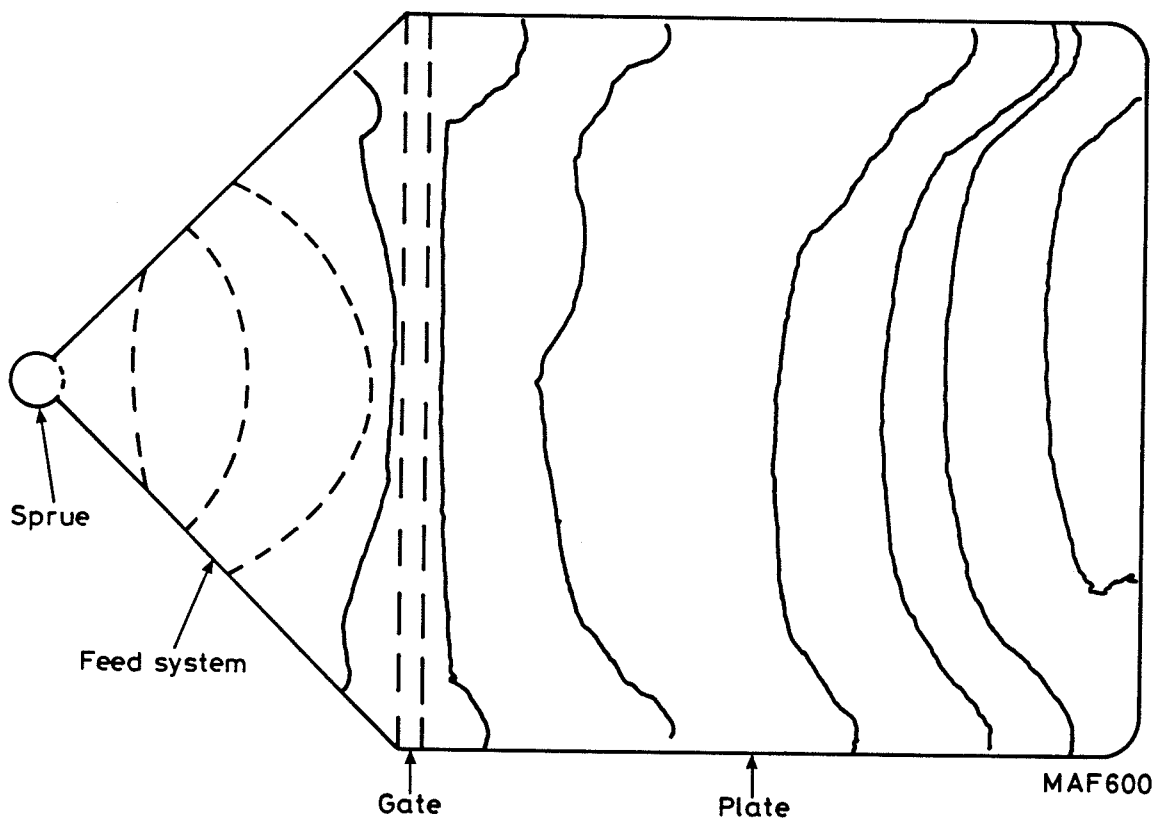


Figure 9 Short-shot filling profiles obtained using feed design 1, 1 mm thick gate, 2 mm thick plate for GFPBT. Mould trial reference: MAF600 series.

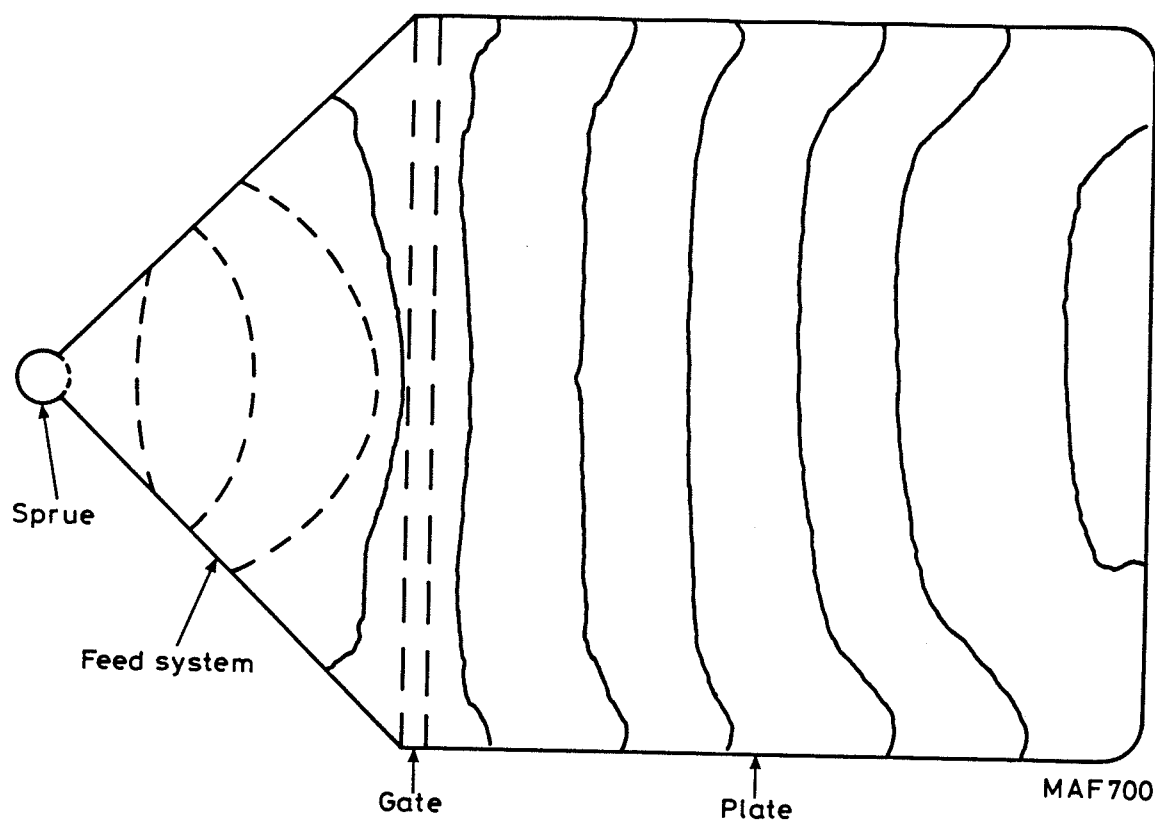


Figure 10 Short-shot filling profiles obtained using feed design 1, 2 mm thick gate, 2 mm thick plate for GFPBT. Mould trial reference: MAF700 series.

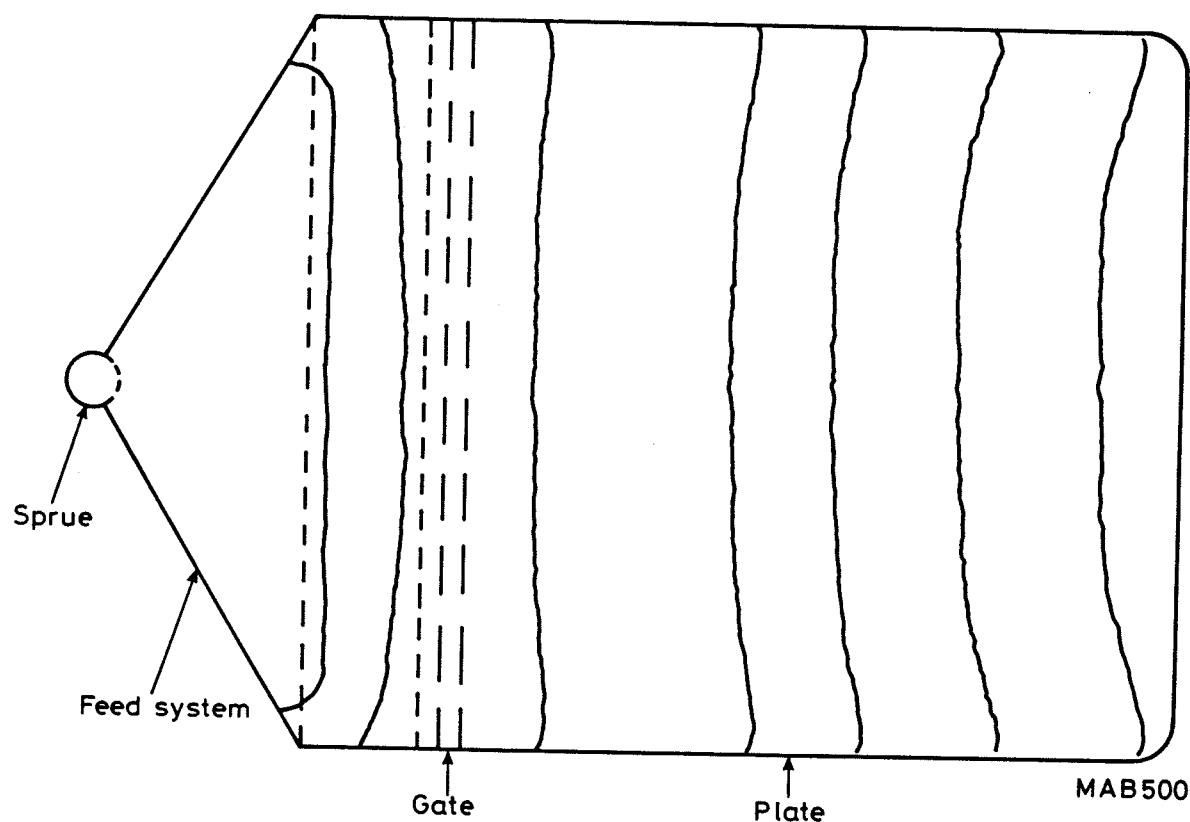


Figure 11 Short-shot filling profiles obtained using feed design 2, 1 mm thick gate, 2 mm thick plate for GFPP. Mould trial reference: MAB500 series.

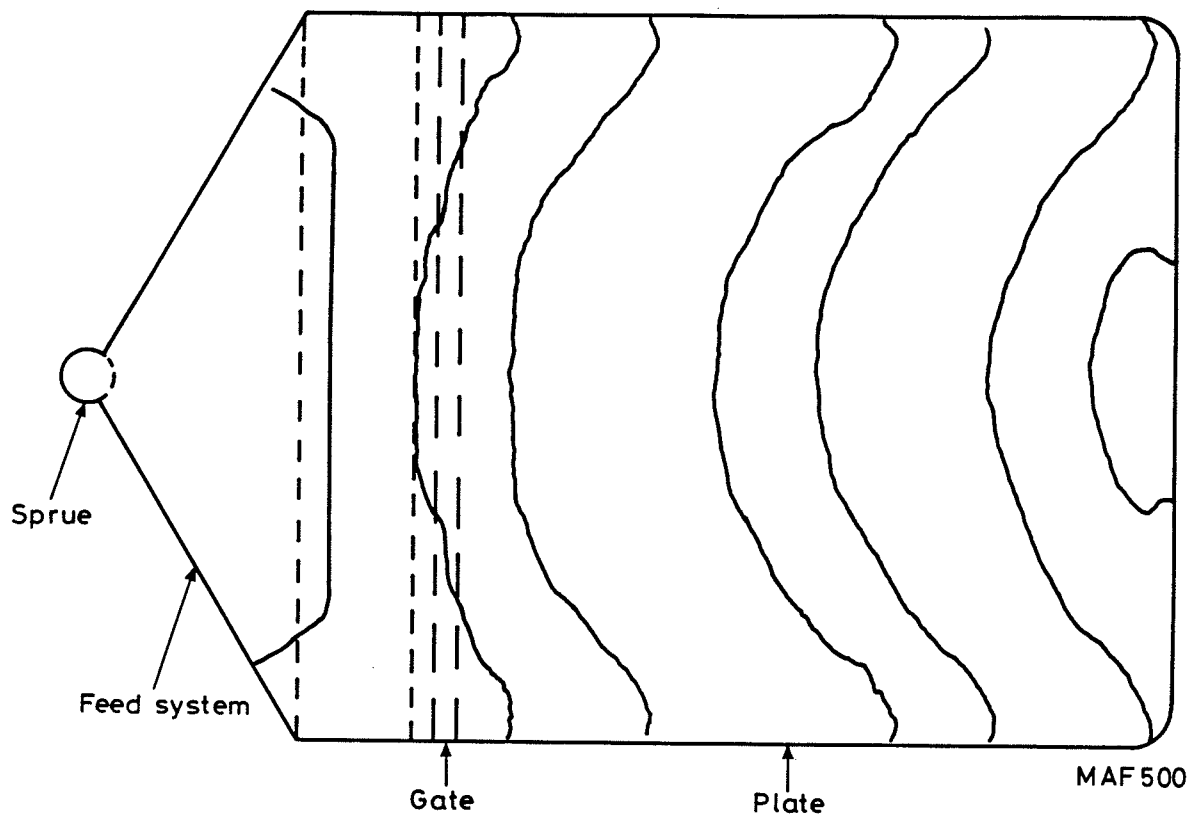


Figure 12 Short-shot filling profiles obtained using feed design 2, 1 mm thick gate, 2 mm thick plate for GFPBT. Mould trial reference: MAF500 series.

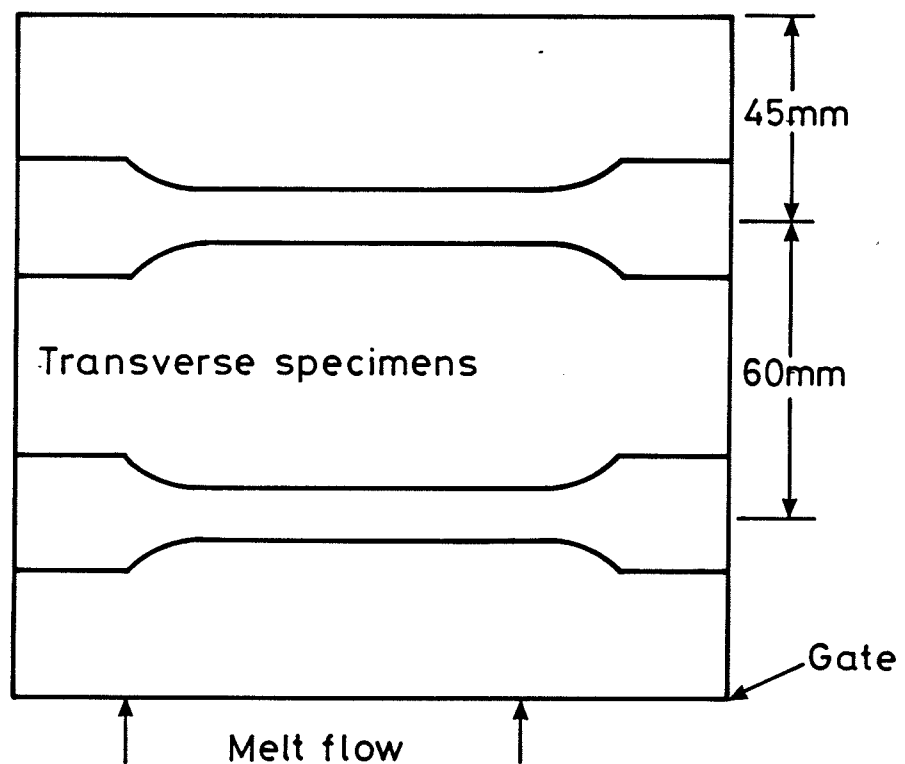
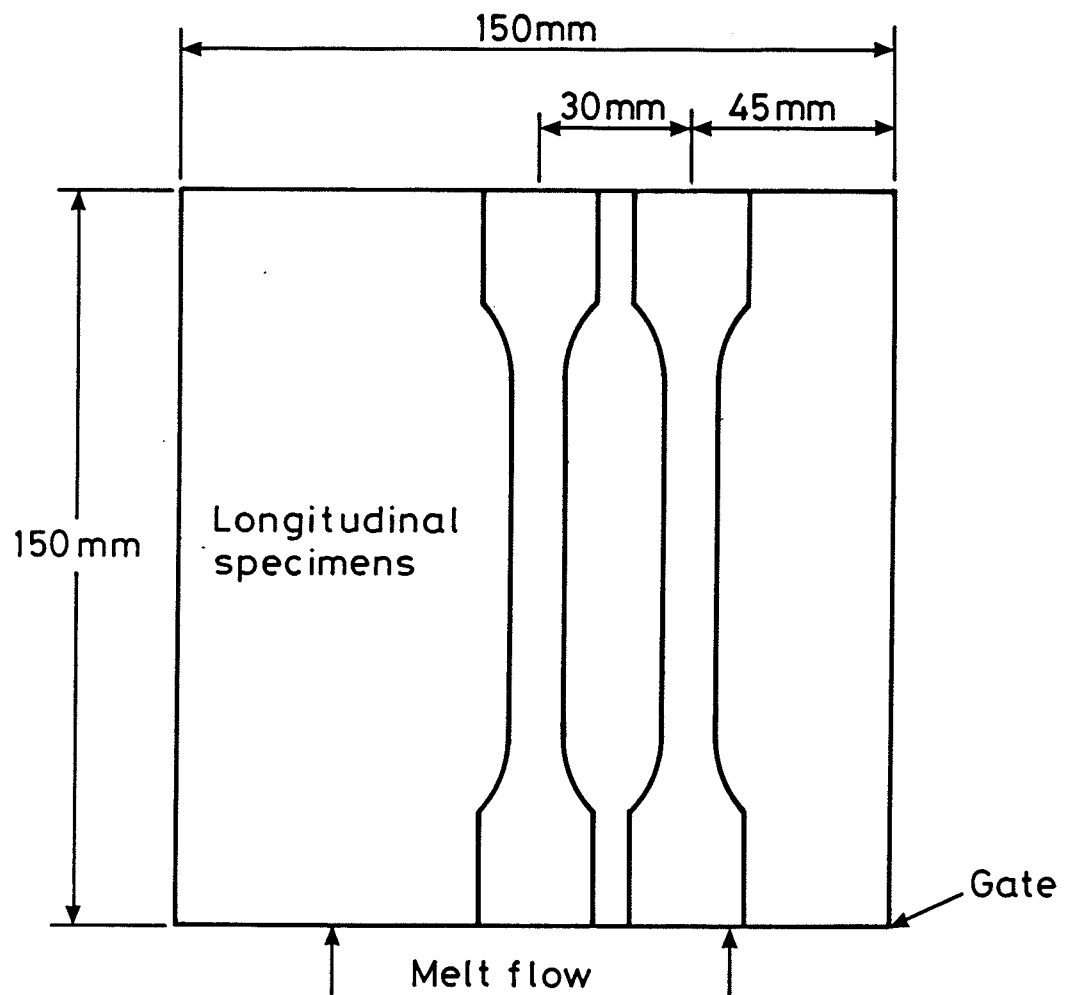


Figure 13 Test specimen positions within the plate geometry.