Numerical simulation of the compression flow of a polymer disk for modelling hot embossing processes

M. Sahlia, b, c, C. Roques-Carmesa, J.C. Gelinb and C. Khan Malekc

a Surface Microanalysis Laboratory (LMS), ENSMM, 25030 Besançon Cedex, France.
b FEMTO-ST Institute, ENSMM, 25030 Besançon Cedex, France.
c FEMTO-ST Institute, CNRS UMR 6174, LPMO Department, 25044 Besançon Cedex, France.

Abstract

The modelling of the hot embossing process requires accurate determination of the polymer flows. In this work, we propose to use numerical models to describe the flow of a polymer disk in compression deformed at a constant temperature under a constant load in axisymmetric loading conditions.

In the simulation, the polymers exhibit viscoelastic or viscoplastic behaviours depending on the experimental conditions. The relative displacements of the plates lead to important modifications of the radial and transversal flows.

The experimental observations associated to this modelling analysis were conducted on cyclo-olefin-polymer (COP) and cyclo-olefin-copolymer (COC) that were respectively compressed at a temperature above the glass transition temperature of each polymer (Tg+30°C).

Keywords: hot embossing, numerical modelling

1. Introduction

The flows of polymer materials associated with the forming by micro hot compression or hot embossing [1, 2] correspond to both configurations described in fig.1: one at constant volume, the other one under constant load [3].

Only hot embossing at constant volume will be treated in this paper. The objective is to describe not only the contribution of parietal flows with barrelling deformation types of the free edges of the material (see Fig. 2), but also the filling mode of engraved surface cavities (peaks or valleys) as is detailed in various references. The modelling approach based on the finite elements method uses a viscoelastic behaviour law for the polymer, which is integrated within the basic data of the selected simulation software (LsDyna©).

2. Modelling the squeezing of a polymer disk

The proposed analysis concerns a polymer part with cylindrical shape that is compressed between two rigid parallel platens (see Fig. 3). The symmetry of the problem allows using 2D axisymmetric assumptions resulting in a mesh composed respectively with 850 and 462 nodes.

The modelling of the hot embossing process is based on the hypothesis of an isothermal compression of amorphous polymer materials carried at constant volume. Under these assumptions, the compression is analysed in two typical cases:

- in the first one, the lower plate remains fixed, whereas the upper plate moves under a constant load equal to -6kN,

- in the second one, both plates are moving in opposite direction and a constant load equal to 3kN is applied on each plate.
The Young’s modulus of the polymer materials is comprised between 2200 and 3200 MPa and the materials follow a viscoelastic behaviour law. The Young’s modulus of the rigid plates is estimated to 2.1.10^5 MPa and their Poisson ratio to 0.3. The friction coefficient between the polymer part and the platens correspond to μ=0.01.

3. Simulation results

In the first case corresponding to tests carried out with only one moving plate, the result of the squeezing process is illustrated in Fig. 3 that respectively describes the radial (see Fig. 3a) and transversal (see Fig. 3b) flow velocity components.

The radial velocity has naturally a zero value on the symmetry axis and exhibits the highest value on the external parts of the barrelled shape. A dissymmetric behaviour can moreover be observed in the closest area to the moving plate. In addition, a gradient of transversal velocity can be noted on the whole thickness of the material. The highest value corresponds to the area in contact with the moving plate and the zero value corresponds to the fixed plate as illustrated in figure 3b.

In the second case corresponding to the tests performed by compression between two mobile platens, the data obtained were collected in figure 4. In this configuration the radial velocities exhibit a symmetrical profile whereas the transversal velocities have a zero value on the neutral axis.

Fig. 3. Simulation of the flow of a COC 5013 polymer disk between two plates, the upper plate being the mobile one: (a) radial velocity component (s⁻¹); (b) transversal velocity component (s⁻¹).

In addition, the profiles of the radial and transversal velocity fields resulting from both configurations are illustrated in figure 5.

Fig. 4. Simulation of the velocities resulting from the squeezing of a polymer disk in COC 5013 between two movable platens: (a) radial velocity components (s⁻¹); (b) transversal velocity components (s⁻¹).
4. Experiments

4.1. Materials

To validate the proposed simulation approach, hot compression tests were carried out on amorphous polymer materials with density in the order of 1.01. The selected samples have a cylindrical geometry corresponding to Ø49x8 mm. Table 1 shows the material and processing parameters used for the COP and COC polymers.

4.2. Experimental procedure

Different tests were performed in axisymmetrical and isothermal conditions using a 100kN tensile test machine to determine the compression flow. Two diameter 60mm parallel rigid platens were selected, the upper one being fixed and the lower one movable. The sample was placed between these two platens.

The whole system was heated up to a temperature higher than the glass transition temperature \( T_g \) of the polymers. Once this temperature was reached, the mobile plate moved under constant load till the thickness of the sample was reduced to 60% in regard to its initial thickness.

The transversal deformations were recorded during the squeezing. The radial deformation was measured using a sliding guide enabling the displacement of a 3 mm diameter cylindrical rod. The rod was in contact with the polymer sample on one side and with a LVDT linear displacement sensor on the other side.

Tests in the temperature range 130–170°C were realized. The temperature during the experiments was recorded using a thermocouple.

5. Results and discussion

Fig. 6 shows the experimental variation of the radial strain rate vs. axial strain rate.

Table 1

Characteristics of COC et COP materials and associated parameters used for performing hot embossing process

<table>
<thead>
<tr>
<th>Material</th>
<th>( T_g ) (°C)</th>
<th>( E ) (MPa)</th>
<th>MFI (g/10min)</th>
<th>Compression temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COP1020R</td>
<td>102</td>
<td>2200</td>
<td>20</td>
<td>130</td>
</tr>
<tr>
<td>COP480</td>
<td>138</td>
<td>2200</td>
<td>20</td>
<td>170</td>
</tr>
<tr>
<td>COPE48R</td>
<td>139</td>
<td>2500</td>
<td>25</td>
<td>170</td>
</tr>
<tr>
<td>COC6013</td>
<td>140</td>
<td>2900</td>
<td>14</td>
<td>170</td>
</tr>
<tr>
<td>COC5013</td>
<td>136</td>
<td>3200</td>
<td>48</td>
<td>170</td>
</tr>
</tbody>
</table>

These results were obtained by recording the point of highest barrelling deformation (point1 cf.fig. 7) with regard to a point close to the interface of the moving plate (point 2 cf.fig. 7).
As expected, the agreement between the experimental values and these ones resulting from the model is verified and is illustrated in figure 8.

![Graph of comparison between experimental velocities and values resulting from the model](image)

Fig. 8. Comparison between experimental velocities and values resulting from the mode (COP 480).

In addition and in order to determine the influence of the polymer characteristics on the previous experimental data, the variation of the radius of the polymer disks was assessed vs. compression time. As expected, a clear reduction of the disk radius vs. consistency of the polymer was observed.

![Graph of time variation of the disk radius under a constant force for different polymers](image)

Fig. 9. Time variation of the disk radius under a constant force for different polymers

It has been proved that one can accurately account for modelling the main parameters, and the results of the introduced models are in good agreement with the experimental observations.

These numerical calculations performed for platens without cavities show that the flow profile is symmetrical in the case where both platens move whereas when only one platen moves and the other is fixed, the flow profile is not symmetrical. This behaviour has consequences on the filling of identical cavities that would be included on both platens: in the first case, cavities on both sides would fill at the same time, whereas in the second case, the cavities on the fixed platen would fill after the cavities on the mobile platen. Experiments to validate this result are presently under course.

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References


6. Concluding remarks

The modelling of the hot embossing process is based on the hypothesis of an isothermal compression of amorphous polymer materials carried at constant volume.

It describes the flows during the hot compression of these materials and is experimentally validated by measurements performed on instrumented tensile test equipment.

The modelling parameters concern the load, the temperature, the friction conditions between the polymer and the plates but are also related to the material viscous properties of the polymers.