CAPCE

Thrust Area Update:

Thermoplastic Processing

Dr. Kurt W. Koelling, Program Manager

Feature Project

Thin Wall Injection Molding of Thermoplastic Microstructures

By Liyong Yu and Yi-Je Juang (Koelling and Lee)

Thin-wall injection molding is a key technology allowing the low-cost mass production of microstuctures, such as devices with surface-relief microcomponents widely applied in micro-optics, micro-fluidics, medical and biotechnology. Research was performed to gain a better understanding of important parameters in injection molding of thin-wall microstructures.

A conventional Computer Numerical Control (CNC) machining technique was applied to make a 1.5" diameter mold insert. The mold insert has three channels with depths ranging from 50 µm to 300 µm.

For the molding materials, polymethyl methacrylate (PMMA) and optical quality polycarbonate (OQPC) were selected, which are common polymer substrates in bio-MEMS application. For material characterization, the dynamic complex viscosity of PMMA and OQPC was measured as a function of temperature and shear rate using a Rheometrics Mechanical Spectrometer (RMS-800). The experimental data were shifted and the master curves fit by the Williams-Landel-Ferry(WLF) equation:

$$\log\frac{\eta T_r \rho_r}{\eta_r T \rho} = \frac{-C_1(T - T_r)}{C_2 + T - T_r} = \log a_T$$

Figure 1 shows that the shifting factor a_T of OQPC is more sensitive to temperature than in PMMA. This is consistent with our experimental results: in order to completely fill the thin cavity, OQPC requires a higher minimum injection speed than PMMA.

The injection molding experiments were conducted on a 200-ton Sumitomo high-pressure, high-speed machine. The melt temperature was controlled at 290°C for OQPC and at 215°C for PMMA. The mold temperature was 30°C, the holding pressure 350 psi, and the holding time 5 secs. Injection speeds of 0.5, 1 , 2, 4, 8, and 16 in./sec. were tested.

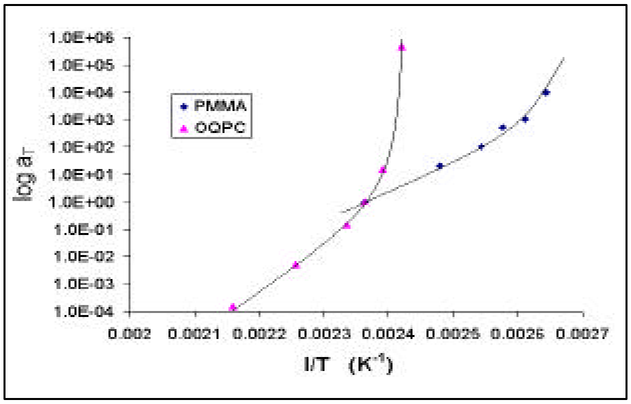

Fig. 1 Shifting factor -temperature relationships for PMMA and OQPC

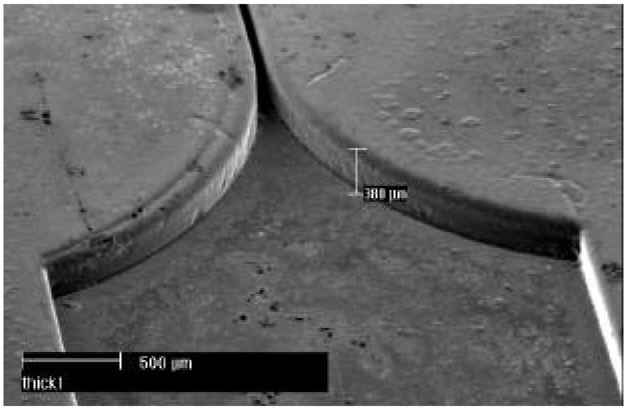

Fig. 2 SEM photo of molded structure(from well to channel).

The replication accuracy of the fabricated parts was investigated. Scanning Electron Microscope (SEM) photos were taken to measure the dimensions of the molded parts. The molded part in Figure 2 shows that the shapes from the well to the channel are replicated very well, although the surface quality is imperfect because the master was not polished or chrome-coated.

We also qualitatively examined the amount of residual stress in the molded parts by observing birefringence patterns. Injection molding carries a certain amount of residual stresses in the molded parts, leading to different refractive indices in different directions. At a lower flow rate, the disk shows a larger variance. When the injection rate is increased, the transmitted light becomes more uniform as the residual stress decreases. This is because at a higher flow rate the polymer can quickly fill the mold and relax before solidification occurs.

The following conclusions are drawn from our work to date. Using CNC machining methods, metal mold master structures on the order of 50 mm can be fabricated. Such structures can be replicated by thin-wall injection molding with PMMA and OQPC. Through study of the influence of injection molding parameters on the molded parts, as well as the use of different injection speeds, we showed that a fast speed is favorable for mold filling and better residual stress distribution. For these reasons, we conclude that replicating the metal inserts by straight injection molding yields a stable and feasible process for mass fabrication.

Supercritical Fluid Assisted Polymer Blending

By Mark Elkovitch (Lee and Tomasko)

PE 2207, a rubber copolymer consisting of 80% ethylene and 20% methyl acrylate, is used to increase toughness of glassy polymers. The methyl acrylate portion of PE 2207 is compatible with polymethyl-methacrylate (PMMA) but not with polystyrene (PS). Supercritical carbon dioxide was added to blends of PMMA/PE 2207 and PS/PE 2207. Improved blending of the PMMA was observed. A reduction in the domain size of the rubber phase and possibly an enhancement of polymer miscibility occurred. Results indicate that CO_2 improved the dispersion of the rubber phase, causing increased flexibility in the final blends.

Compounding and Processing of Nanocomposites

By Hua Wang and Changchun Zeng (Lee and Koelling)

Nano-clay based polymer composites are prepared by direct melt intercalation in a twin-screw extruder. It was found that 5-10 wt. % nano-clay greatly increases the viscosity and elastic modulus, and largely decreases the water absorption of polymers that are compatible with nano-clay (e.g. nylon 6). For polymers that are incompatible with nano-clay (e.g. PP), the presence of clay in the range of 5-10 wt. % has little effect on melt viscosity and elastic modulus. The addition of nano-clay greatly changes the morphology and its development in nylon 6/PP blends. PMMA nanocomposites are prepared by both in-situ polymerization and direct melt intercalation. Both exfoliated and intercalated structures are observed by X-ray diffraction (XRD) and Transmission Electron Microscopy (TEM). Mixing conditions, clay surface treatment, and reaction conditions all affect the final structure of the composites. Ultrasonic mixing is proven an effective way to enhance clay dispersion in the composites.

PVC Degradation during Injection Molding Using Computational Techniques

By Liyong Yu and Jose L. Garcia (Koelling)

Research was performed to gain a better understanding of PVC injection molding. Both spiral and radial flow geometries were evaluated using a finite difference scheme, in order to gain detailed information about viscous heating during injection. The degree of degradation was evaluated by implementing a tracer method. The simulation shows a maximum temperature near the wall, due to the competition between viscous energy dissipation and heat conduction. Good agreement with experiments was achieved for a rectangular cavity. A C++ program was implemented using modified converging criteria and the computational speed was improved. The effect of part thickness was examined. Further work involves short shot prediction, new algorithms for tracers near the melt flow and frozen layer, and analysis of the inertial and flow effects on degradation kinetics.

Viscoelastic Analysis near the Glass Transition Temperature in the Micro-Embossing Process

By Yi-Je Juang(Lee,Koelling)

In MEMS (micro electromechanical systems), the hot embossing process is a major fabrication technique for making polymer microstructures. In order to minimize the process cycle time, the embossing temperature is set slightly above the glass transition temperature (T_g), while the de-embossing temperature is slightly below T_g. Since the polymer is deformed near T_g, its flow behavior during molding is substantially different from high temperature processes such as injection molding and extrusion. A set of experiments was carried out using different rheometers for rheological characterization. Both dynamic and transient shear viscosity measurements were conducted using the RMS-800. For the tensile test, the Instron was used at low temperature and the Rheometrics Elongational Melt Rheometer (RME) at high temperature. A micro-embossing process is being developed based on molding experiments, rheological characterization and viscoelastic modeling.

Co-injection Molding of Thermoplastic Foams

By Susan Porter (Koelling)

A potential new research area involves studying co-injection molding with thermoplastic foams. This area is of interest because it creates products that are lightweight, have excellent insulating properties and provide adequate product strength. The process involves using two reciprocating screws, one for the outer plastic shell and the other for the thermoplastic foam core. The outer shell is injected in the mold first, followed by the foam to hollow it out. The thermoplastic foam core is formed using carbon dioxide as a physical blowing agent. Refrigerator casings are an example of a possible application of this research, where good insulation and a hard, smooth outer surface are needed and a lightweight product is desirable.

Gas-Assisted Injection Molding

By Yijie Wang (Koelling)

The displacement of a low viscosity fluid in higher viscosity material causes the formation of a long bubble penetrating through the high viscosity fluid. This leaves a thin coating on the wall, which has important applications in gas-assisted injection molding. The effect of fluid rheological properties on the fractional coverage left by the bubble was studied under isothermal conditions. In the experiment polymer solutions of different shear thinning properties were used as high viscosity fluids, and silicon oil was used as the displacing fluid. The result shows that as the absolute viscosity increases, the thickness of the high viscosity fluid on the wall also increases. In the future, non-isothermal conditions and different tube geometries may be used to study the process in more detail.

Extrusion of Polystyrene Microcellular Foam with Supercritical CO2

By Xiangmin Han (Koelling, Tomasko, and Lee)

Microcellar foams are usually characterized by a cell size smaller than 10 microns and a cell density greater than 10^9 cells/cc. The microcellular foaming process has three basic steps: mixing, nucleation and cell growth. By applying the Sanchez-Lacombe equation of state, the solubility of CO_2 in polystyrene was calculated from 20 to 200℃ under pressures from 0.69 to 20 MPa. The contraction flow in the extrusion die was simulated by the FLUENT computational code to decide the location of nucleation starting position. At present, experiments are underway to identify optimal operating conditions. With an increased die temperature, cell density decreases and cell size increases. With the same die temperature and an increased screw rotation speed, more cells are nucleated and the cell size becomes smaller. To date, cells smaller than 14 microns and a cell density greater than 2.5×10^8 cells/cc have been manufactured.

- continued on page 7 -