PRIMARY EXPERIMENTAL STUDY ON MICROCELLULAR INJECTION MOLDING USING NEWLY-DEVELOPED EQUIPMENT*

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Abstract

Microcellular injection molding using supercritical fluid (SCF) as blowing agent attracts more and more interests. There are still many difficulties in microcellular injection molding, such as decreasing equipment cost, controlling cellular morphology, and increasing feasibility. In this work, primary microcellular injection molding experiments were carried out on newly-developed equipment, which includes a conventional injection molding machine, SCF conveying unit, specially designed nozzle, and mold. SCF from syringe pump was injected into the polymer melt between the screw and nozzle during the injection phase. Then, polymer/SCF melt was pushed by screw through a mixing element, and was injected into mold cavity after forming homogeneous phase. Polystyrene (PS) was selected to mold the standard tensile and impact specimens using the equipment. The required minimum filling pressures during the microcellular and conventional injection molding were compared. The densities of microcellular injection molded specimen and its solid counterpart were measured. The cellular morphologies at different positions of microcellular injection molded specimen were observed using scanning electron microscope (SEM). The tensile and impact strengths of standard specimens were tested. The results showed that introducing SCF during molding decreased the filling pressure and material usage. There were different cellular structures along and perpendicular to the direction of melt flow. The newly-developed equipment has several advantages, such as low cost, easy operation, and extensive use.

***Keywords*:** microcellular injection molding, supercritical fluid, polystyrene

Introduction

Microcellular injection molding process can de described briefly as follows. First, supercritical fluid (SCF) is injected and blended with polymer melt in the barrel of injection molding machine to create a single-phased polymer/gas solution. Then the polymer/gas solution is injected into mold cavity and nucleated. Finally a part with cellular structure is molded. Microcellular injection molding can produce part with excellent dimensional stability while using lower filling pressure, shorter cycle time, and less material [1−3]. Because of the advantages of microcellular injection molding, more and more researchers put the interests on this process [4]. Microcellular injection molding equipment was developed by several institutions, such as Trexel [5], IKV [6], University of Toronto [7], and University of Warwick [8].

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In this work, primary experimental study on microcellular injection molding was carried out using newly-developed equipment. Polystyrene (PS) standard tensile and impact specimens were molded using the microcellular and conventional injection molding method. The filling pressure and specimen density as well as the cellular structure at different positions of specimen were investigated.

Experimental

Experimental Equipment and Material

The schematic of the microcellular injection molding equipment used in this work is shown in Figure 1. The equipment consists of a conventional injection molding machine (CJ80M3V, Chende), SCF conveying unit, specially designed nozzle, and standard specimen mold. Among them, the SCF conveying unit includes a syringe pump (ISCO 500D) and conveying components. SCF from syringe pump is injected into the polymer melt between the screw and nozzle during the injection phase. Then, polymer/SCF solution is pushed by the screw through a mixing element to form single-phased polymer/gas solution. The single-phased solution is injected into mold cavity and nucleated. Finally, the part with microcellular structure is molded.

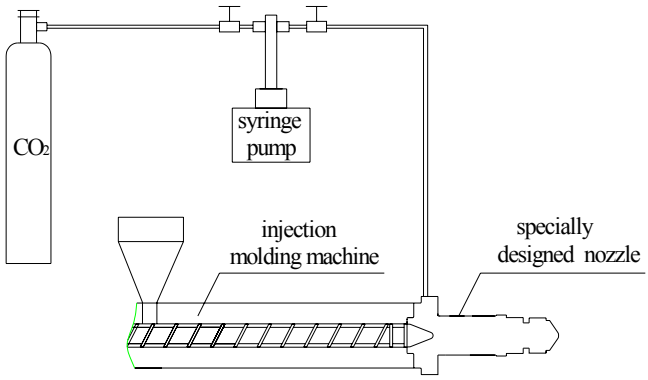

Figure 1. Schematic of Microcellular Injection Molding Equipment

The PS with a melt index 5.1 g/10 min (ISO 1133:1997) produced by DOW chemical company was used in this work. Industrial CO_2 with a purity of 99.5% was directly used as a foaming agent.

Experimental Procedures

The viscosities of PS were measured using Haake on-line rheometer at 190, 230, and 250℃, respectively. The microcellular injection molded specimen and its solid counterpart were prepared at barrel temperatures of 150-220-230-185-180℃ (from hopper to nozzle).

The minimum filling pressure, defined as the required minimum set injection pressure for filling the mold cavity completely in this work, in microcellular and conventional injection molding were compared. The densities (ρ) of the specimens were calculated by Equation (1), after measuring the weight (m) and volume (V) of the specimens.

$$\rho = \frac{m}{V} \tag{1}$$

The microstructure at different positions of the microcellular injection molded specimen was observed using scanning electron microscope (SEM). The detailed positions are shown in Figure 2. A_i, B_i, and C_i (i=1, 2) are three ordinal positions on the mid-plane of the specimen along the flow direction. The subscripts 1 and 2 represent the positions near the surface and at the center of the specimen, respectively.

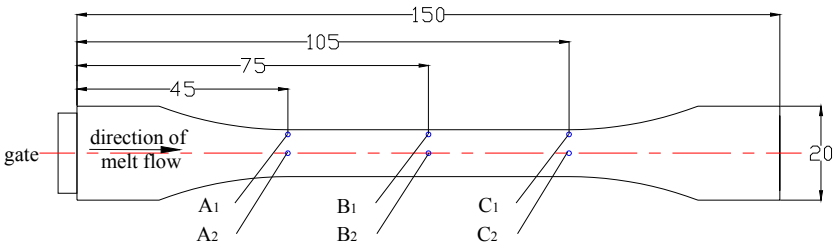

Figure 2. Positions in Specimen Selected to Observe the Cell Structure
(All dimensions are in mm)

Results and Discussion

Figure 3 shows the curves of shear viscosity vs. shear rate of PS at different temperatures. It is obvious that the temperature has an obvious effect on the PS shear viscosity. The shear viscosity of PS at 190℃ is about 3 times of that at 250℃ and 2 times of that at 230℃.

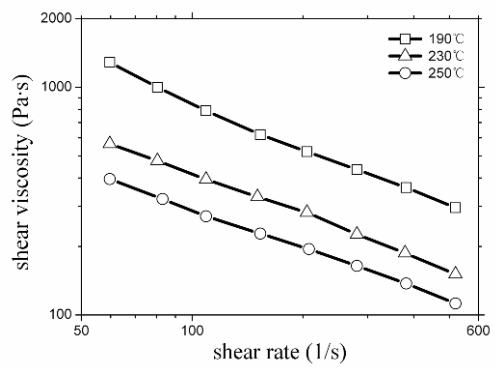

Figure 3. Shear Viscosity vs. Shear Rate of PS at 190, 230, and 250℃

As shown in Figure 4, the minimum filling pressure decreases from 30% to 12% of the rated injection pressure when introducing SCF during molding. This result can be attributed to the fact that viscosity reduction of PS melt when introducing SCF and the help for filling cavity from melt expansion due to cell nucleation and growth during molding. Figure 4 also shows that the densities of microcellular and conventional injection molded specimens are 0.88 and 1.03 g/cm^3, respectively. The former is about 85.4% of the latter.

Figure 5 shows the SEM micrographs at the different positions of the microcellular injection molded specimen. In general, most cells have a diameter smaller than 100 μm, and a few cells have a diameter 100~200 μm. As can be seen, the cell number near the surface of specimen is fewer than

that at its center. Moreover, cell diameter near the surface is smaller than that at the center. This may be because that the temperature of melt near the surface of the mold decreases firstly due to the heat transfer with mold, which makes melt viscosity increase largely due to the fact that the temperature has an obvious effect on the PS viscosity (as shown in Figure 3), and so cell nucleation and growth are retarded to some extent. It can be also seen from Figure 5 that both diameter and number of cell increase along the direction of melt flow. This is due to that the pressure far from the gate is lower than that near the gate because of the pressure loss during filling the mold. The lower pressure facilities the cell nucleation and growth.

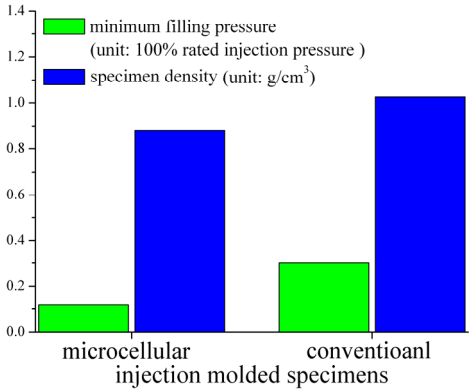

Figure 4. Comparison of Minimum Filling Pressure and Specimen Density

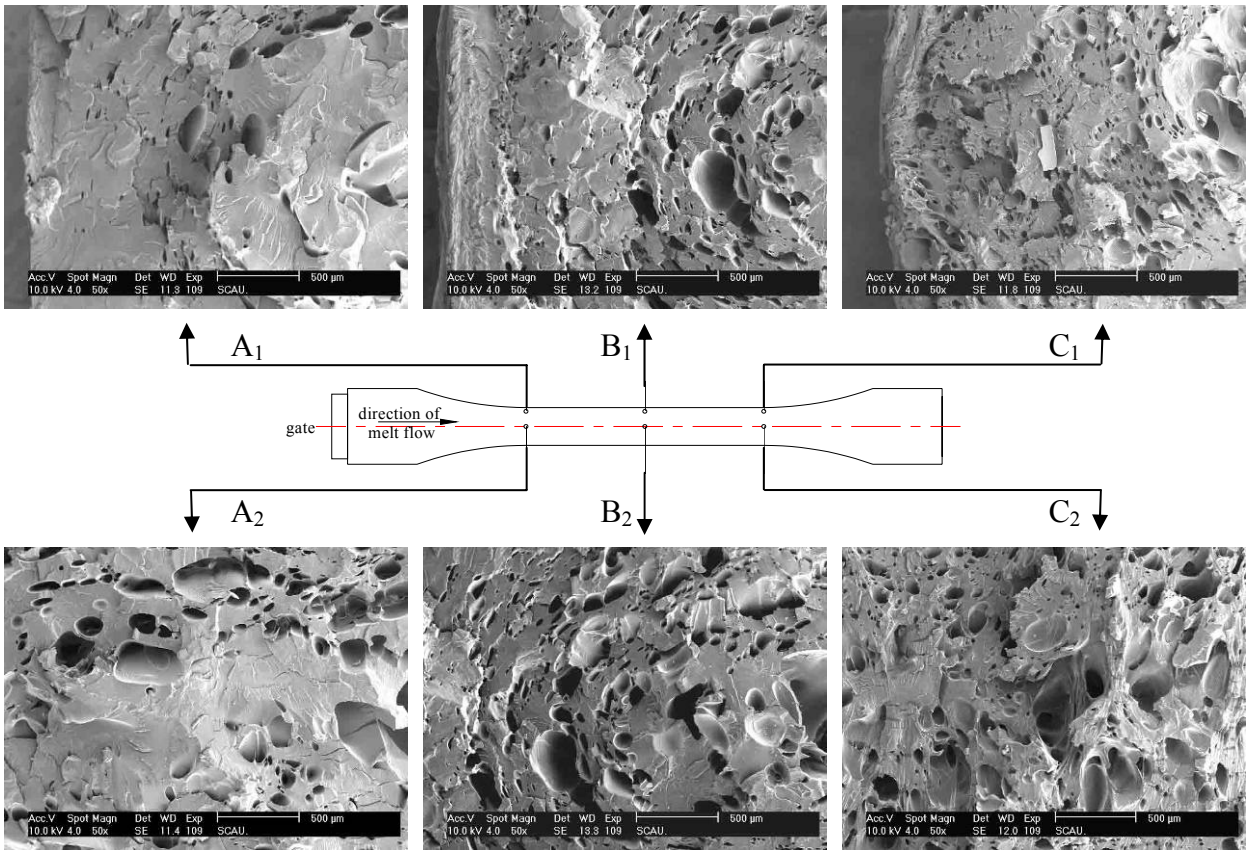

Figure 5. SEM Micrographs at Different Positions of Microcellular Injection Molded Specimen

The results of standard tensile and impact tests will be presented at the podium presentation.

Conclusions

The microcellular structural specimens were prepared using the newly-developed microcellular injection molding equipment by authors. The results demonstrated that the required minimum filling pressure was reduced by about 60% when introducing the SCF during molding. The specific density of microcellular injection molded specimen decreased about 15% compared to that of conventional injection molded specimen. Most cells in the microcellular injection molded specimen had a diameter smaller than 100 μm. Moreover, the difference cellular structures of microcellular injection molded specimen along and perpendicular to the direction of melt flow was observed. Both diameter and number of cells increased with the distance from the gate. The cell number and diameter near the surface of specimen were fewer and smaller than that at its center.

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