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Injection molding of micro patterned PMMA plate

Yeong-Eun YOO[1], Tae-Hoon KIM[1], Tae-Jin JE[1], Doo-Sun CHOI[1], Chang-Wan KIM[2], Sun-Kyung KIM[2]

1. Department of Nanomanufacturing Technology, KIMM, 171 Jang-dong Yusung-gu, Daejeon 305-343, Korea;
2. Department of Product Design and Manufacturing, Seoul National University of Technology, 183 Gongneung-gil Nowon-gu, Seoul 139-743, Korea

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Abstract: A plastic plate with surface micro features was injection molded to investigate the effect of pressure rise of melt on the replication of the micro structures. Prism pattern, which is used in many optical applications, was selected as a model pattern. The prism pattern is 50 μm in pitch and 108° in the vertical angle. The overall size of the plate was 335 mm×213 mm and the thickness of the plate varied linearly from 2.6 mm to 0.7 mm. The prism pattern was firstly machined on the nickel plated core block using micro diamond tool and this machined pattern core was installed in a mold for injection molding of prism patterned plate. Polymethyl methacrylate (PMMA) was used as a molding material. The pressure and temperature of the melt in the cavity were measured at different positions in the cavity and the replication of the pattern was also measured at the same positions. The results show that the pressure or temperature profile through the process depends on the shape and the size of the plate. The replication is affected by the temperature and pressure profiles at the early stage of filling, which is right after the melt reaches the position to be measured.

Key words: micro prism pattern; injection molding; replication; pressure profile; temperature profile

1 Introduction

Micro features on the surface are well-known to have significant effects on optical or mechanical properties[1−3]. These surface micro features are increasingly employed to enhance the functionality of applications including optical components for LCD or solar panel. Diverse surface features have been proposed and some of them show excellent efficiency or functionality[4−6].

Most applications employing the micro features need mass production process and the injection molding may be preferred for micro patterned plastic product. Since the functionality or efficiency of the surface structures generally depends on the shape and the size of the structure itself or the array of the structures, it would be very important to replicate the features precisely as being designed during the molding process.

Injection molding process, in general, consists of filling, packing, cooling and releasing as shown in Fig.1. As a preparation step, micro pattern is pre-machined on the surface of a metal block to have reverse image of surface pattern to be molded, and the block is assembled into the mold cavity. At filling and packing step, the thermoplastic melt is injected and pressurized to fill the cavity and also the micro surface structures on the micro machined block surface in the cavity. Then the injection molded plastic article with surface micro pattern is released from the mold after being cooled and solidified.

In injection molding process, the hot melt starts to be cooled and solidified rapidly from the skin region after it is injected into the relatively cold cavity. This cooling and solidifying from the skin cause severe under-molding problem especially for micro surface patterns existing in the skin region, as shown in Fig.2. Therefore, it is one of the major technical issues to enhance the degree of replication of the micro surface pattern and some researches on this have recently been reported[7−12].

Despite the injection molding of micro surface pattern was studied extensively, the pressure or the temperature was rarely measured at the micro pattern region in the cavity during the process to investigate the

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Corresponding author: Doo-Sun CHOI; Tel: +82-42-8687124; E-mail: choids@kimm.re.kr

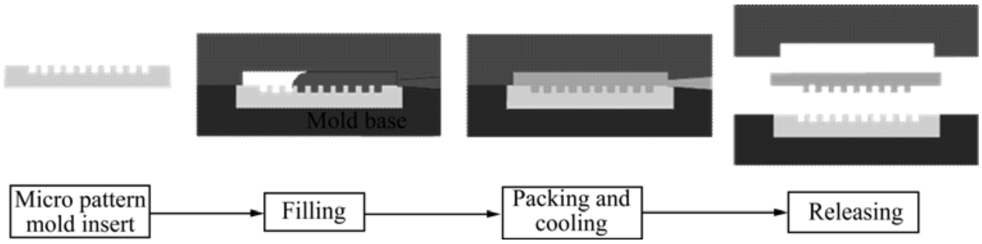

Fig.1 Procedure of injection molding process

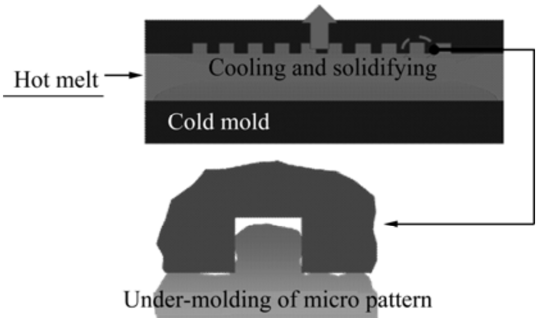

Fig.2 Poor replication of micro surface structure due to melt cooling at skin region

replication of micro surface pattern. According to some previous researches, the replication of the micro pattern depends on the processing conditions including mold temperature, injection rate, packing pressure and time or melt temperature, etc, but the replication will vary significantly according to the size, shape or configuration of the cavity for the same processing conditions. For more fundamental understanding on the micro pattern replication, the melt pressure is measured at the micro pattern region directly during the molding process to figure out how the pressure affects the replication of the micro pattern at different regions in the cavity.

2 Preparation for injection molding

2.1 Dimension of plate and prism pattern

A wedge-type of plate was designed to have a continuous micro prism pattern on one side. The shape of the plate was 335 mm×213 mm and the thickness of the plate varied linearly from 2.6 mm to 0.7 mm as shown in Fig.3. The prism pattern was designed to pitch of 50 μm along the major axis and vertical angle of 108°. The height of the prism pattern was about 18 μm (Fig.3).

2.2 Micro machining of prism pattern on core block

For injection molding of micro prism patterned plate, a prism pattern need to be machined firstly on the metal block to be assembled into the mold system. The micro pattern machined block and the image of the micro pattern are shown in Fig.4. For this experiment, a nickel

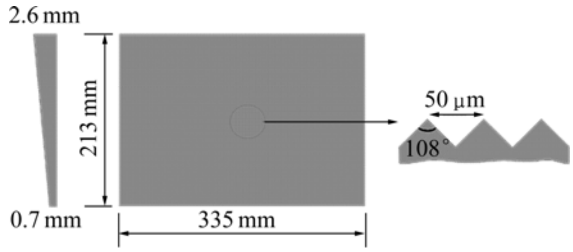

Fig.3 Shape and dimension of plate and micro prism pattern on surface

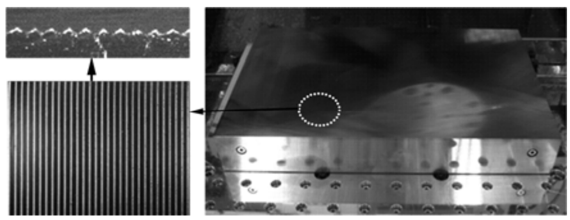
Fig.4 Nickel coated core block and micro prism pattern machined on block

electro-plated block is micro-machined for prism pattern by shaping process using a micro diamond cutting tool.

2.3 Mold system and installment of pressure transducers

An injection mold was designed to have two-plate structure as shown in Fig.5. A fan gate was used at the center of the edge of the thicker side. This fan gate covered about one third of the whole edge. Two strain gage pressure transducers (Dynisco PT449) were mounted on the surface of the cavity to measure the melt pressure during the molding process at two different positions (Fig.5), where the replications of the pattern were expected to show the largest variation. This transducer had 6 mm-diameter of sensing area and 0−1.36 kN/cm^2 of measurement range. For measurement of the surface temperature in the cavity during the process, encapsulated K type thermocouple modules were installed into the pattern block at 9 positions of the stationary mold half as shown in Fig.5. The cross-sectional view of the thermocouple unit installation is shown in Fig.6.

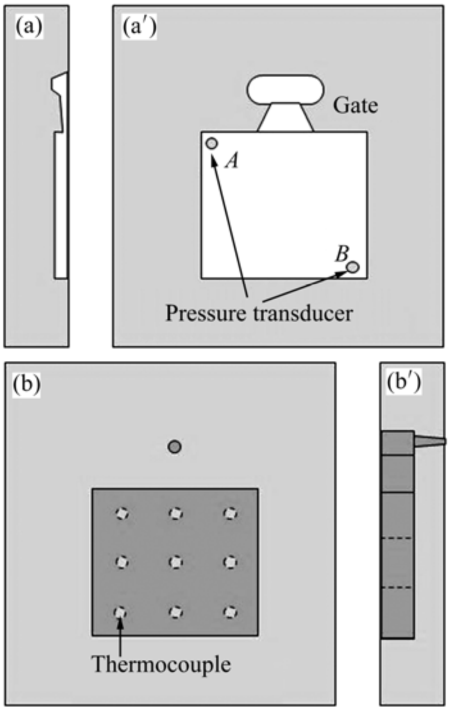

Fig.5 Schematic diagrams of mold design and configuration of sensors: (a), (a′) Moving mold half (cavity); (b), (b′) Stationary mold half (core)

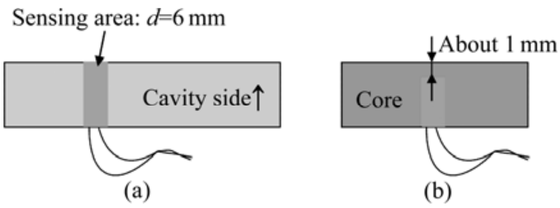

Fig.6 Cross-sectional views of pressure (a) and temperature (b) sensors installed

Several channels were embedded in both mold halves to control the surface temperature of the cavity and the core by circulating heating fluid through these channels which were connected to two heat exchangers (mold temperature controller) using oil as heating fluid. The temperature range of these mold temperature controllers was between 40 °C and 160 °C.

3 Injection molding experiment

An electric injection molding machine (Sumitomo SE 550D) was used for molding experiments, which has a clamping capacity of 550 t. As a molding material, PMMA from Asahi was used, which was an optical grade PMMA(Grade of 80 N).

For molding with PMMA, the barrel temperature of the machine was set to about 230 °C for the highest temperature region. After a series of preceding molding experiments to find a reasonable process window for the plate, some parameters including the injection rate, packing pressure, time and mold temperature were pre-determined for injection molding to investigate the spatial variation of the micro pattern replication on the plate. The injection rate was set to 80 mm/s in the region of about first 30% of the total injection volume and 120 mm/s for other regions. For the packing stage, pressure of 90 MPa was applied for 10 s to prevent the post-molding deformation of the plate such as sink or warpage. The mold temperature controller was set to 120 °C for the moving half and the cavity side, 110 °C for the stationary half and the core side. Under the molding conditions described above, the melt pressure and the mold temperature were measured in the cavity through the filling, packing and cooling step. The sampling rate for the melt pressure was set to 1 kHz for fine resolution at the filling stage where the pressure increases very steeply.

After molding, the micro prism pattern was measured to estimate the degree of replication at two different positions as shown in Fig.5. For position *B*, the last part to fill is relatively far away from the gate compared to position *A*, which is filled at early stage of filling.

4 Results and discussion

Fig.7 shows an injection molded PMMA plate and micro prism patterns at 2 different positions, *A* and *B* as shown in Fig.5. The micro prism pattern at position *B* turns out to be molded better than that at position *A* which is much closer to the gate than position *B*. From a rough estimation of the degree of the replication, the ratio of the molded pattern height to the master pattern height, the pattern at position *A* shows approximately 70% of replication, while the pattern at position *B* shows over 90% of replication. This difference results from the pressure and temperature of the melt during the molding process. The melt pressure and temperature will vary according to the size and shape of the cavity, and also the processing conditions. Fig.8 shows the melt pressures measured during the process at positions *A* and *B* in the cavity. When the melt reaches the position where a pressure transducer is installed, the pressure starts to increase. As shown in Fig.8, the melt reaches position *B* approximately 0.4 s later after the melt reaches position *A*. The position *B* is almost the last region to fill, which is far from the gate, so the melt will experience lower pressure at this position compared to position *A*. This may result in worse replication at position *B*, but the replication turns out to be better at position *B* for this experiment as being frequently told by some engineers from industry.

For replication of the most surface micro pattern, the melt needs to flow into the micro pattern engraved on

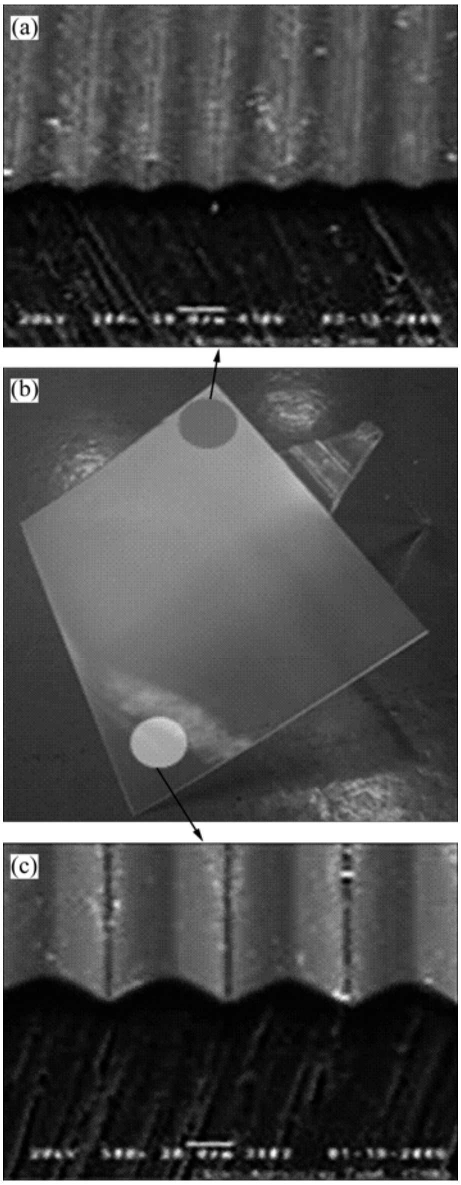

Fig.7 Injection molded plate and micro prism at two positions

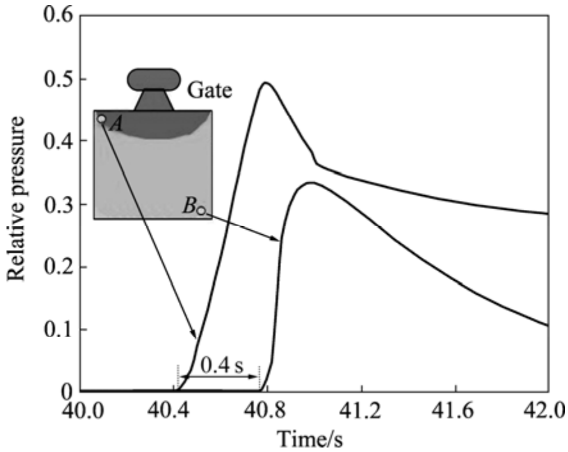

Fig.8 Relative pressure curves for two positions of PMMA plate during molding process

the surface of the cavity. Considering the dimensional difference between the cavity and the micro pattern, the viscous polymer melt is reasonably assumed to fill the cavity firstly and then the micro pattern after the melt gains enough pressure to flow into the micro pattern on the mold surface[7−9, 11]. Therefore, the replication of the micro pattern will depend on how quickly the hot melt flows into the micro cavity on the surface before losing its fluidity due to the cooling and solidification. This indicates the pressure at early stage is more responsible for the replication of the surface micro pattern in the injection molding process and the pressure rise will depend on various factors including melt temperature, cavity thickness or geometry of the cavity.

In Fig.9, the melt pressures measured at positions *A* and *B* are adjusted to have the same reference point by shifting the pressure curve along the time axis. These adjusted pressure curves enable us to compare the pressure rise directly after the melt touches each position. As shown in Fig.9, the overall pressure or peak pressure

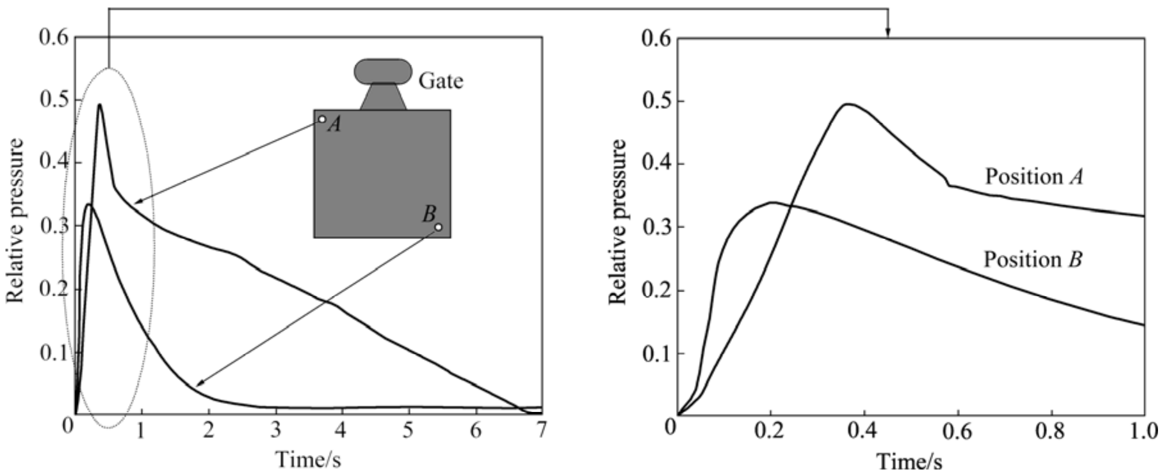

Fig.9 Comparison of relative pressure rise right after melt reaching positions *A* and *B* of PMMA plate

is higher for position *A* than that for position *B*, but the pressure at position *B* increases more rapidly than that at position *A* right after the melt reaches each location. In general, the pressure is expected to rise more rapidly near the gate due to higher pressure. For the wedge-type of plate molded in this study, however, the melt near position *B* is inferred to experience more rapid pressure rise, which is thinner region compared to that near position *A*. In addition, the cavity becomes filled completely right after the melt passes position *B* resulting in steep pressure rise. This more rapid pressure rise at position *B* may explain better replication of micro pattern at position *B* than that at position *A*, where the melt becomes cooled and solidified near skin layer significantly till the melt gains enough pressure to flow into the micro pattern on the surface of the cavity.

5 Conclusions

1) The replication of a surface micro pattern was investigated in thermoplastic injection molding process. A 50 μm pitch of prism pattern was adopted for molding experiment and the injection molded pattern was evaluated at two different positions where the replication was believed to show the largest difference. From the predetermined molding conditions through a series of experiments, the replication of micro prism pattern was found to be better in the end-of-fill region than in the region close to the gate.

2) An explanation was made by measuring and analyzing the pressure in the cavity throughout the molding process. It was found that the melt pressure rise in short period right after the polymer melt reaches the micro pattern may be more responsible for the replication of the surface micro pattern.

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