

## Relationship between Replication and Structure of Micro/Nano Molded Parts

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### Introduction

In recent years, quality improvement and higher performance of molded products are keenly required, especially for precise and micro-scale products such as optical devices, medical applications, information and communication applications, and others. These micro-scale system technologies (MST) will have a far-reaching influence on device manufacture in the near future. MST is also described as micro electro mechanical systems (MEMS). During the last two decades, numerous studies have addressed the research and development of MEMS. An intense research interest has prevailed in micro-scale polymer processing because of the growing emphasis on MEMS<sup>1-6)</sup>. In micro-scale polymer processing, e.g. micromolding, micro-scale molded products were placed in three categories; there are molded products with micro-structured surface, molded products with milligram less than one pellet weight, and products with micro-precision. However, micro-scale polymer processing technology is still in a trial and error stage. Moreover, it is difficult to achieve an optimum product design. Most studies have limited their scope to issues of processability and surface structure observation; the internal structure and properties of the molded products have not been deeply discussed. Molding conditions have a marked effect on structural development and final properties of molded products. Therefore, precise investigation of relationships between molding conditions and structure and physical properties is indispensable. Recently, we have performed micromolding, and have analyzed high-order structure and final properties on micro thin-wall molded products deeply<sup>7-10)</sup>. In this study, thin-wall injection moldings with micro and nano-scale line and space patterns were carried out. Replication quality in transcription, optical properties and internal structure of molded parts were also investigated by changing the injection speed, mold wall temperature and the cavity thickness.

### Experimental

Several commercial polymers were used in the micro- and nano-molding to study how different materials with different structural formation and replication during the process. There polymers included: polypropylene (PP) (Prime Polymer Co., Ltd, F-704NP, MFR=6.8), cyclo-olefin copolymer (COC) (Topas Advanced Polymers GmbH, Topas 6013, T<sub>g</sub> = 140°C, MVR = 14 (260°C/2.16 kg)), poly(methyl methacrylate) (PMMA) (Mitsubishi Rayon Co., Ltd, Acrypet MD001, MFR=6.0), and polycarbonate (PC) (Mitsubishi Engineering-Plastics Co., Iupilon H-4000, MFR=63).

For micromolding, we used the intelligent analysis system which consists of a precision micromolding machine, multi-pass rheometer, and PVT properties measurement apparatus<sup>7-10)</sup>. In this time, a small electric injection molding machine in this system was used for molding. Molding conditions such as injection temperature, mold temperature, injection speed and holding pressure were selected to each polymer, and effects of molding conditions on replication and higher-order structure of molded parts were investigated.

The shape of mold cavity was 9 x 9 mm square. We prepared two kinds of micro surface features. One is composed of 4 groups of lines and spaces, which are aligned in the direction to melt flow. Lines in each group had different widths (50 to 200 μm) and depths (50 to 200 μm). The total number of lines was 34. Another shape was grid of 400 μm square with 100 μm in height. Each grid was located in every 100 μm space. At both molds, the cavity thickness of the central region at both was varied to 0.1, 0.3, and 1.0 mm. We also prepared two kinds of nano-scale surface features. There are composed of 2 groups of lines and spaces. There are two different intervals of space, 1 μm and 10 μm, respectively. At both molds, the shape was 600 nm in width with 530 nm in height.

We investigated processability through flow length measurement of molded parts using the polariscope and digital camera. Replication ratio, which was defined as the ratio of height and depth of surface

structures of used molds and molded parts, were analyzed by scanning confocal laser microscope (SCLM) and AFM measurements. We also analyzed the molecular orientation of the parts using the polariscope and polarizing optical microscope (POM) with Berek compensator. In addition, a skin-shear-core structure of molded parts analyzed by polarizing microscope after thin section was cut parallel to the MD-ND plane from the molded parts with a microtome.

### Results and discussion

We measured an interference fringe of molded products, which correlates closely with optical retardation and residual strain. Interference color was observed clearly near the gate and disappeared toward the flow end. This means that residual strain near the gate is the largest than any other position. Interference color of grid-patterned parts was almost same in the TD direction because of stable polymer flow. On the other hand, interference fringe color was different in the TD direction in line-patterned parts. In the case of short shot parts, a different flow length at each line. These tendencies reveal that polymer flow in the cavity is influenced by surface patterns. Contacting mold surface accelerates polymer cooling. At higher cooling rate, the viscosity of melted resin increased and solidification of melted resin occurred rapidly. So the longest polymer flow was achieved at lines of 200 μm in width and depth, the deepest line, because of moderate cooling.

In order to analyze the skin-shear-core structure and local optical retardation of molded parts with micro-grid surface, thin section cut parallel to the MD from the molded parts. Surface pattern affects distribution of higher-order structure inside the parts. Cross-section of molded products observed under polarizing optical microscope is shown in Figure 1. Existence of skin-shear-core structure inside the molded parts was confirmed. We also observed micro-features on surface had low molecular orientation, and the shear region exhibited below the micro-features. An inner core region with low molecular orientation was formed. At high injection speed, the skin-shear-core structure also was observed, and the thickness of shear layer became thicker whereas the thickness of skin was decreased. At high mold temperature, the thickness of shear layer became thinner. Moreover, the thickness of skin-shear region decreased at the flow end portion. From these observations, it was revealed that the injection molding condition affects the thickness of skin-shear region. The development of a skin-shear regions disturbed polymer flow inside the molded parts. We also found out that the distribution of replication ratio on the molded surface was influenced by the thickness of skin-shear regions.

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### References

- 1) L. Weber et al., *Kunststoffe*, 88, 1791(1988)
- 2) J. Zhao et al., *Proceedings of PPS-18*, 163 (2002)
- 3) S. Y. Yang et al., *Intern. Polym. Process.*, 354 (2002)
- 4) P. D. Coates et al., *ANTEC Tech. Paper 2004*, 757 (2004)
- 5) C. Chang et al., *Proceedings of PPS-20*, 121 (2004)
- 6) W. Michaeli et al., *ANTEC Tech. Paper 2004*, 752 (2004)
- 7) H. Ito et al., *J. Soc. Polym. Process. Symposia Tech. Paper*, 375 (2004)
- 8) H. Ito et al., *SPE-ANTEC 2005 Tech. Paper*, 894 (2005)
- 9) H. Ito et al., *Theoretical Appl. Mech. Jpn.*, 54, 263 (2005)
- 10) H. Ito et al., *J. Soc. Polym. Process.* '05 Tech. Paper, 253 (2005)

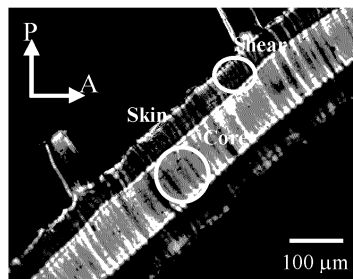


Figure 1 Polarized microphotograph for cross-section of PP parts with grid-structured surface. Injection speed is 150 mm/s and holding pressure is 20 MPa. Injection and mold temperatures are 220 and 40 °C, respectively.