1 Introduction

Injection molding technology can replicate precise µm-wide structures such as a 1µm-pitch grating pattern. It cannot, however, obtain precise mm-wide forms such as a fine flatness of 0.1µm / 10×10mm or a fine straightness of 1µm / 50mm because the mold cannot control physical phenomena of a plastic material in a cavity during processing cycle.

Generally, injection molds do not have enough sensors / actuators to measure / control the solidification process in each zone of the cavity. For example, plastic near an edge of the box replication solidifies quickly, causing a large bent at the center of the box. Moreover, the plastic is not uniform, creating a different characteristic during each cycle.

We introduce a “smart palm-size injection mold”, which has micro-sensors for pressure / temperature / displacement in the cavity zones and has piezo elements and heaters for controlling these parameters for each cycle. The target replica products are small, for example, an optical f-θ lens, a plastic-bonded hard magnet, a micro multi-pins connector and so on.

2 Device for the Experiment

We used a compact hydraulic injection molding machine JUKEN JMW-015S-5t. This machine has a φ16mm vertical injection screw with a maximum injection pressure of 133MPa and a horizontal mold clamping unit whose available clamping force is 49kN. The mold temperature control is integrated in the machine using two band heaters and a thermo couple mounted to the surfaces of the movable part of the mold.

The schematic of prototype-I “the smart palm-size injection mold” is shown as fig. 1. There are three heat flux sensors 2.5×2.5, 18mm long in the movable insert die for measuring the heat flux and temperature at each zone of the cavity. Also, there is a force sensor behind two of four ejector pins for measuring the cavity internal pressure and a displacement sensor on the parting plane for measuring the cavity volume change. There are two micro ceramic heaters 20×10×2mm in the stationary insert die to control the heat flux in each zone of the cavity.

Fig. 2 shows the schematic of the test part. A 30×15mm plate with four 5mm-height-ribs. The thickness of the plate varies from 1 to 2mm to cause the ununiform temperature distribution when it solidifies.

3 Results

3.1 Cycle-by-cycle temperature control experiment

As an example of cycle-by-cycle temperature control, we measured temperature variance at the center of the cavity across different cycles, and studied what control can improve the process and what effect it may have on the shape of the molded product. We measured the temperature at the center of the cavity for 20 shots without control and 20 shots with control. Fig.3 shows the data, respectively. Note that the graphs superimpose the 20 shots on top of each other.

When there was no control, as the graph shows, the temperature changed drastically three seconds after the start of injection. Fig.4 shows the temperature of each shot after 4.5 seconds. The figures clearly indicate that control reduces the temperature variance. Thick parts of the molding show shrinkage when the temperature declined and fluctuated. We found out that it is possible to eliminate the shrinkage of the molding by reducing the variance in temperature.
Fig. 1 Schematic of “the smart palm-size injection mold”

Fig. 2 Schematic of the test part

The reading of the pressure sensors or the displacement sensors did not show wide variance or discontinuity. Therefore, we believe that the sudden decrease in temperature was caused as follows: Local minor shrinkage occurred to the plastic near the heat current sensor, which caused a gap to be formed between the hot resin and the sensor and furthermore prevented the actual temperature from reaching the sensor. Small heat current sensors may be more effective in detecting local shrinkage at the center of the molding than pressure sensors or displacement sensors.

3.2 Zone-In-Cavity temperature control experiment

We conducted two experiments of controlling zone-in-cavity temperature.
For Case A, we examined the shape of the product side as we varied the surface temperature of the heater. Fig. 5 shows the shape of the molding sides versus the heater temperature. The figure indicates that higher heater temperature reduced the amount of deformation in the middle of the side walls. When the heater temperature was 175 degrees Celsius, the end points near the heater deformed by 3µm in the opposite direction. This indicates that local heating caused local deformation that affected the overall shape of the product. These facts suggest the possible application of fine temperature control for precise shape production with high degree of straightness or for precisely molded optical lenses.

For Case B, we attempted to eliminate the shrinkage at the top surface by uniformly cooling the center and the end points of the molded product using feedback heater control. Fig.6 shows the shape of the top surface with and without control provided. The figures show that the control reduced the shrinkage which were present at the top end points and at the root of the ribs when there was no control. In other words, controlling local temperature allows better shape control of the external appearance of the molded product without changing the injection pressure or the metal model temperature. It is generally known that increasing pressure or temperature of the plastic improves shrinkage. In such cases, however, when increasing the pressure or temperature is not desired, local heating proves to be very effective for shape control.

Both cases A and B indicate that for further precision with injection molding, a much finer local
temperature control is necessary. The authors are currently investigating the second model, prototype-II
50×50×50mm, 1kg copper alloy mold with a φ2mm ceramic heater and a φ1mm fountain-type temperature
controller. The model is currently in design.

4 Conclusion

(1) The authors developed a small metal mold that allows local temperature control for cycle-by-cycle
and for zone-in-cavity temperature control.

(2) The authors confirmed that temperature control for each cycle managed the temperature variation of
the plastic during cooling, improving the appearance of the final molding.

(3) The authors confirmed that controlling the shape of the molding by controlling local zone-in-cavity
temperature, allows improving the external deformation without changing the plastic pressure or the
metal mold temperature

References

Chin Yan, M.Nakao, T.Go, K.Matsumoto and Y.Hatamura: Injection molding for duplication of
microstructures using mold-core extrusion mechanism and small sensors, 2001, JJSPP Autumn, 139.

M.Yoda, M.Nakao, Chin Yan: Precise / Micro Mold Injection Using Miniature Smart Mold, 2002,
JJSPE Spring, 378.