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The experimental study on the defects occurrence of SL mold in injection molding

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ABSTRACT

Past experience has shown that the defects occurrence in injection-molded parts of metal mold included weld line, flow mark and solid skin. In this study, a thin wall cavity is designed as flow path for plastic injection mold. The injection molding tests were performed by using metal mold and stereolithography (SL) mold to compare with the flow behavior and defects occurrence of flat parts. The experiments were performed with various process parameters to investigate the defects occurrence in the injection-molded parts. The experimental results showed that defects occurrence has close relation with injection speeds and mold temperatures. Flow marks of SL mold occur more easily when the mold temperature and the injection speed are low. Moreover, the injection-molded parts were examined whether the surface defects (flow mark and weld line) occurred and analyzed as the reference for the future SL mold design.

1. Introduction

Injection molding is a high-pressure and high-temperature casting process. Traditional molds are made from steel or other metal materials. The typical molding conditions for plastic materials are the melt temperature of about 200 °C, mold temperature of 40 °C, injection pressure of 40 MPa and cycle time of 10–60 s. So-called stereolithography (SL) mold utilizes SL patterns generated on a stereolithography apparatus (SLA) from 3D Systems as mold inserts in injection molding. However, the tool strength, thermal conductivity and erosion resistance of the SL mold are lower than that of the traditional metal mold. The lower injection pressure is 20 MPa and the longer cycle time is about 240–360 s. The tool life was limited under 200 shots (Jacobs, 1996; Decelles and Barritt, 1996).

Experiments performed by Schepens and Bulters using a novel two color injection molding technique indicated that surface defects were caused by a flow instability near the free surface during filling of the mold (Bulters and Schepens, 2000). These defects, which are referred to as flow marks, or tiger stripes have been observed in a variety of polymer systems including polypropylene (PP) (Bulters and Schepens, 2000), acrylonitrile-styrene-acrylate (ASA) (Chang, 1994) and polycarbonate (PC)/acrylonitrile butadiene-styrene (ABS) blends (Hamada and Tsunasawa, 1996). Therefore, flow marks occur in crystalline and amorphous polymers.

Currently, the flow behavior and defects occurrence of SL mold in the injection molding process is still unclear. In this study, a thin wall cavity is designed as flow path of SL mold. Experiments were performed with various injection speeds

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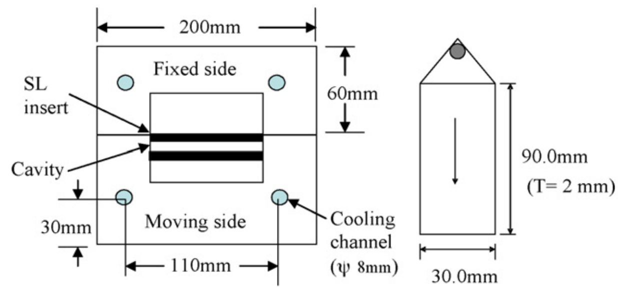

Fig. 1 – Cross-sectional view of the SL mold and molded part.

Table 1 – Test parameters	
Test parameter	The variation range
Mold temperature (°C)	20, 30, 40, 50, 60
Injection speed (cm^3/s)	10, 30, 40, 50, 70

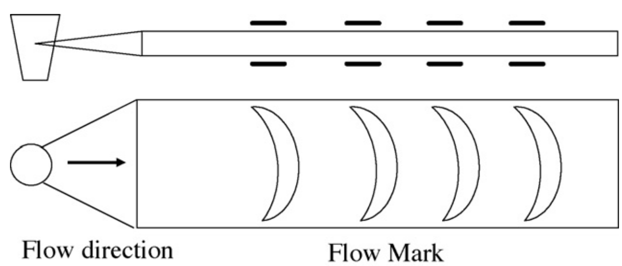

Fig. 2 – Flow mark of the molded part surface.

and mold temperatures to investigate the defects occurrence in the injection-molded parts.

2. Experiments

The basic mold design was based on investigating the flow behavior and defects occurrence. The design guidelines for SL mold were considered (Menges and Mohren, 1993; Li et al., 2000). Flow path design has a fan gate at one end and establishes a nearly ideal linear flow across the entire part during mold filling. A special prototype mold was developed allowing the injection molding of flat parts, with thickness of 2 mm. Fig. 1 presents a cross-sectional view of the SL mold and molded part. The SL epoxy plate with the dimension of 90.0 mm × 30.0 mm × 3.0 mm was fixed for the mold insert. The SL mold inserts were manufactured by SLA 5000 machine, using SL 5510 epoxy-based resin by accurate clear epoxy solid (ACES) build style.

Table 2 – Summary results		
Flow mark	Mold temperature	Injection speed
Large	Room temperature	Low
Middle	Medium	Intermediate
Small	High	High

The injection mold chose a standard mold base manufactured by FUTABA with model MDC SA 2023 60 60 60 S. The injection-molding machine used was ARBURG 270S model. The crystalline and amorphous materials used for injection molding were PP and PC. The molding conditions were listed as the fixed values:

- melt temperature = 210 °C (PP), 300 °C (PC);
- injection pressure = 20 MPa;
- hold pressure/time = 10 MPa/5 s;
- cooling time = 240 s.

The injection speeds and mold temperatures are chosen as test parameters. Table 1 shows the range of the test parameters.

Experimental observations after the injection molding process were performed using visualization and optical microscope (SEIWA Optical Co. Ltd. MS-512-T). Furthermore, surface roughness of the SL insert and molded parts were measured by using a Mitutoyo SURFTEST MST-211 tester. Roughness measurements (Ra) in mold surfaces and critical regions were measured along with the flow direction.

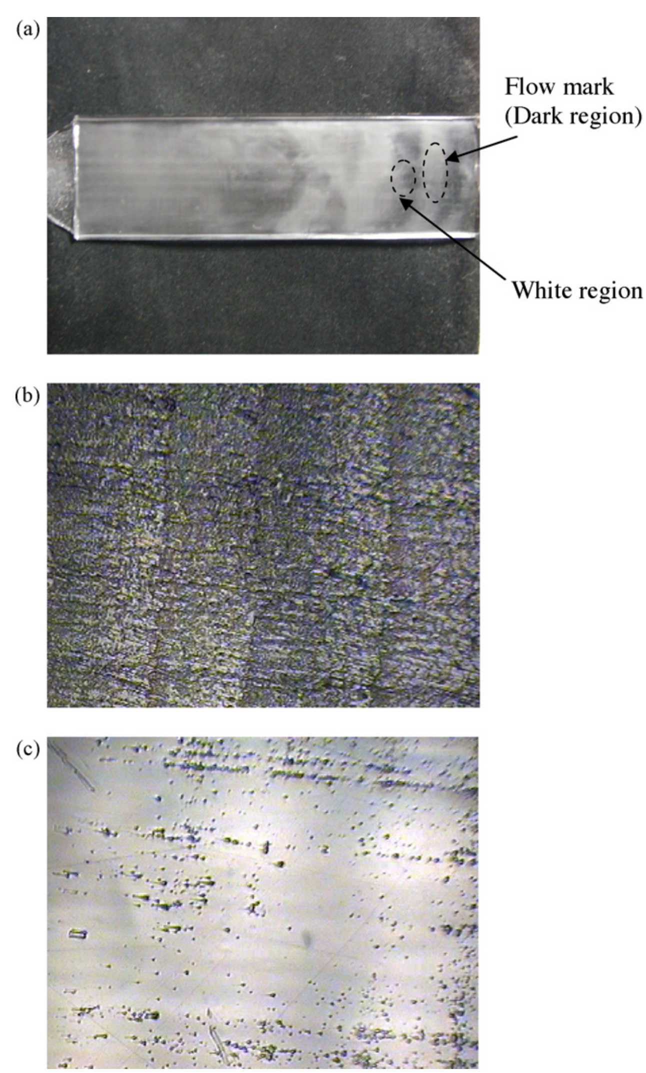

Fig. 3 – (a) Typical photographs of the molded part surface; (b) flow mark region; (c) white region.

3. Results and discussion

3.1. *Experimental observations*

The flow mark is used to describe the phenomenon where a striped pattern is caused by improper flow of the plastic into the mold as shown in Fig. 2. Past experience on the metal mold has indicated that the major contributor to the markings was the mold temperature. The higher temperatures resulted in the lower viscosity and the plastic material in contact with the mold surface is pressurized in a semi-solidified condition. The stripes perpendicular to the flow direction are formed by dark and white region on the surface of the molded part. The operation window can be drawn by the mold temperature and injection speed. Flow marks occur more easily when the mold temperature and the injection speed are low. The summary results are given in Table 2. However, the part surface of PC is observed more easily than the PP by naked eyes. A specific flow mark that is characterized by dull, rough bands roughly perpendicular to the flow direction which alternates on the upper and lower surfaces of the PC mold is shown in Fig. 3. The region with flow marks has a striated surface topology that shows hills and valleys oriented in the flow direction.

The flow mark situation varied with injection speed and temperature are shown in Figs. 4 and 5. As shown in Fig. 4, the larger the injection speed, the smaller the size of the flow marks. With an increase of injection speed, the shear stress also increased, and in turn results in an improved surface. Fig. 5 shows optical micrographs of the flow mark at different mold temperatures of 40 °C and 60 °C. High mold temperature is known to improve surface appearance significantly. For high enough mold temperatures the surface defects

(a) (b) (c)

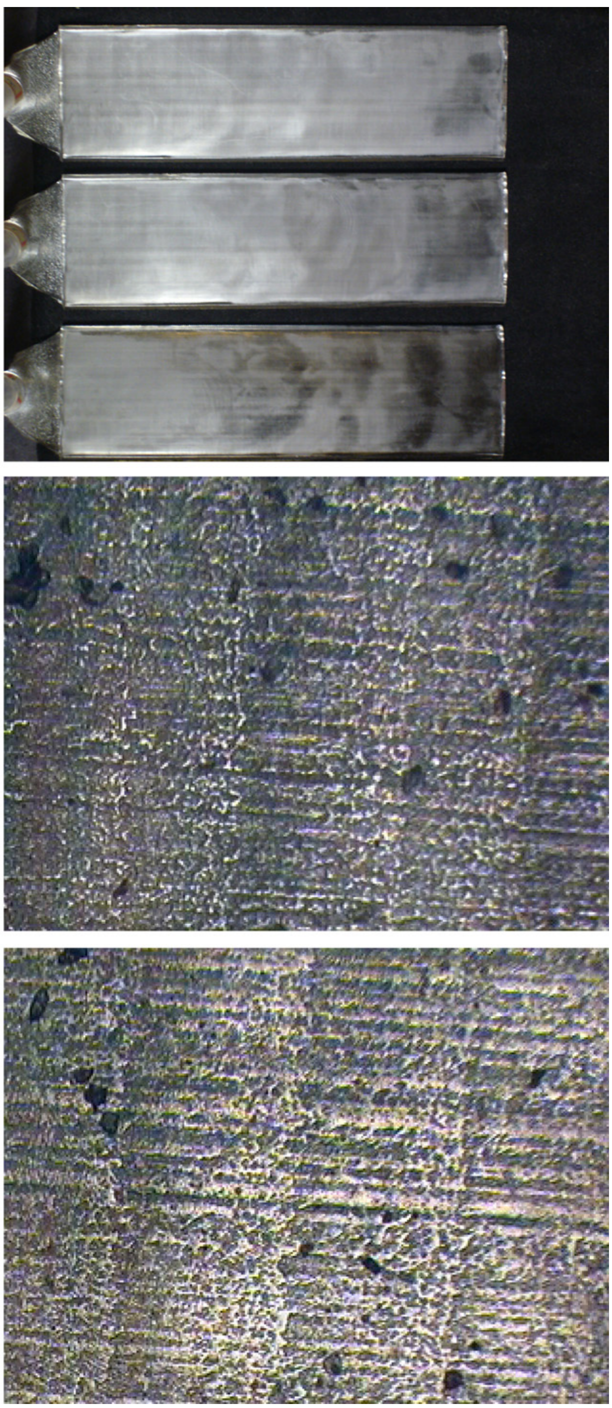

Fig. 4 – (a) Flow mark shape and size of the molded part surface at injection speed of 10 cm^3/s, 30 cm^3/s and 50 cm^3/s; (b) micrographs of the flow mark at 10 cm^3/s; (c) 30 cm^3/s.

(a) (b)

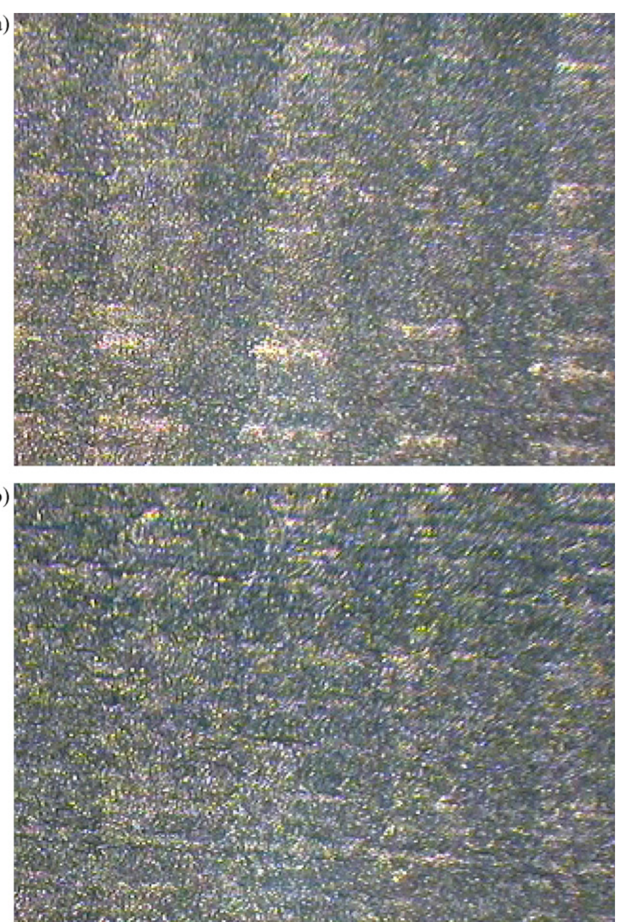

Fig. 5 – Optical micrographs of the flow mark at different mold temperatures of (a) 40 °C and (b) 60 °C.

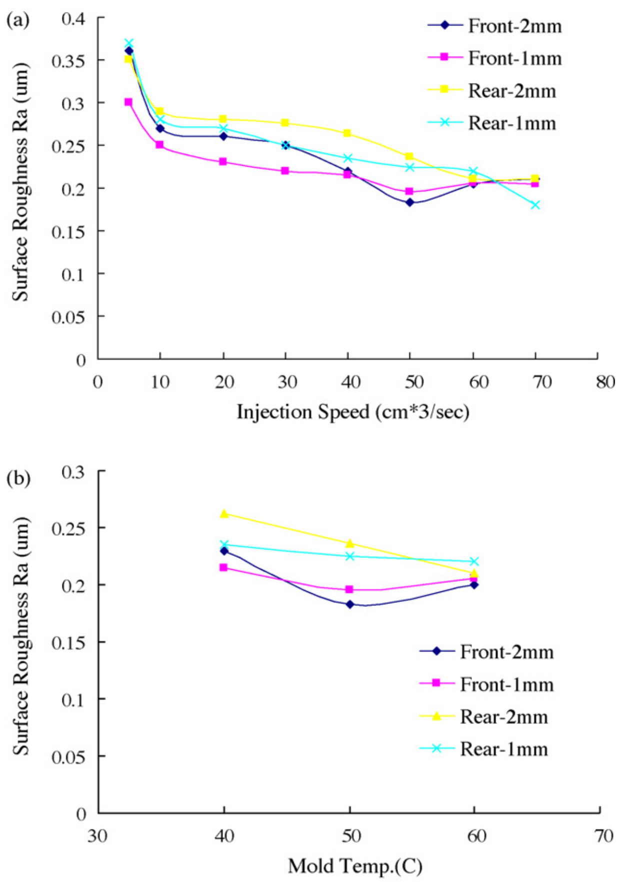

Fig. 6 – (a) Variation of surface roughness with (a) injection speeds and (b) mold temperatures.

disappeared because the polymers were able to relax before solidification.

3.2. *Surface roughness*

The surface roughness (Ra) of the SL insert after the injection molding process was a slight increase from 0.24–0.26 μm to 0.28–0.30 μm. The roughening of the surface of the cavity wall should not be the cause of the defects occurrence.

The molded parts at different injection speed were measured and shown in Fig. 6(a), the larger the injection speed, the smaller the surface roughness of the molded parts. At a mold temperature of 50 °C and an injection speed of 50 cm^3/s or higher, the surface roughness improves to Ra of 0.18–0.23 μm. In Fig. 6(b), the higher the mold temperature, the smaller the surface roughness of the molded parts. At a mold temperature of 50 °C or higher, the surface roughness improves to Ra of 0.20–0.22. μm. By increasing the mold temperature, and the injection speed, the surface roughness of the molded part can be improved.

4. Conclusions

These preliminary results confirmed the defects occurrence of SL mold. It is also noticeable the flow mark has close relation to mold temperatures and injection speeds. However, for high enough mold temperatures, the surface defect disappears because the polymers are able to relax before they solidify. The larger the injection speed, the smaller the size of the flow marks. It seems that the appearance of a flow mark can be improved with increasing the mold temperatures and injection speeds.

There was no significant change on surface roughness of SL mold insert after injection molding. By increasing the mold temperature, and the injection speed, the surface roughness of the molded part can be improved.

Future work will focus on the CAE mold flow analysis and the pressure distribution measurement to analyze shear stress effect.

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