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Experimental Analysis for Factors Affecting the Repeatability of Plastics Injection Molding Tests on the Self-developed Apparatus

Yugang Huang^{#1}, Duxin Li^{#2}, Yuejun Liu^{*3}

[#]State Key Laboratory of Powder Metallurgy, Central South University
Changsha 410083, P. R. China

¹hygzsh@yahoo.com, ²liduxin6404@yahoo.com

^{*}Key Laboratory of Advanced Materials and Technology for Packaging of Hunan Universities, Hunan University of Technology, Zhuzhou 412007, P. R. China

³yjliu_2005@126.com

Abstract - To improve the repeatability of the injection molding test result, the affecting factors were investigated by means of experiments. Besides the traditional processing parameter, the factors of test conditions were also considered. In order to focus on the molding process rather than the molded part, the curve measurement of the melt pressure at the entrance to the nozzle was used as the output characteristic. Experiments for polypropylene (PP) showed that the injected volume was the key processing parameter. Within the test conditions, the injection number is the most important factor. According to the analysis the operating procedure was improved effectively.

Keywords — affecting factors; plastics injection molding; repeatability; test result

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I. INTRODUCTION

The replicated quality of the products is necessary for a plastics injection molding device, especially for an apparatus to test the injection molding process. To improve the repeatability of the injection molding process and ensure the quality of the molded parts, many researches have been undertaken by investigators. Agrawal *et al.* (1987) classified the controlled variables with all-phase control, phase dependent control and cycle-to-cycle control. Jansen *et al.* (1998) investigated the effect of processing conditions on shrinkage in injection molding, and found that the holding pressure was the key parameter. Liu (2001) conducted the experiments with polypropylene on the injection molding machine and concluded that the size of the gate, the melt temperature, and the width of the rib were the principal parameters affecting the sink mark formation. Debondue *et al.* (2004) investigated the effects of the injection temperature and other processing parameters on the weld-line mechanical properties. Kuo and Su (2006; 2007) studied the optimal processing parameters including mold temperature, pre-

plasticity amount, injection pressure, injection speed, screw speed, packing pressure, packing time and cooling time. They applied the optimization of injection molding processing parameters to enhance the quality of liquid crystal display light-guide plates. Sha *et al.* (2007) examined the effects of the barrel temperature, mould temperature, injection speed and distance between the micro-features on the surface quality. Similar works have been done by Attia and Alcock (2009). Wang *et al.* (2008) conducted the experiments to investigate the effect of process parameters and two-way interactions on sink mark depth of injection molded parts. Rizvi and Bhatnagar (2009) studied the effect of various injection molding processing parameters on cell morphology in microcellular foamed polymeric products. Nebo *et al.* (2012) explored the influence of some process parameters on replication of micro-feature during micro-injection molding. Most of these investigations focus on the processing parameters of the plastics injection molding, such as barrel temperature, mould temperature, injection speed, holding pressure and packing time. In our practice

on the injection molding apparatus, the same combinations of processing parameters could not lead to the same results. During experimental tests rather than mass production, there are some other test conditions which should be taken into account for the reproducibility of the test results.

On the other hand, the characteristics for reflecting the quality of the injection molding process varied in the studies mentioned above. Jansen *et al.* (1998) considered the shrinkage. Liu (2001) and Wang *et al.* (2008) minimized the sink marks of molded parts. Debondue *et al.* (2004) cared the weld quality of the molded specimens with the mechanical properties. The screw outer diameter, tensile strength and twisting strength were used as the quality characteristics by Kuo and Su (2006). Rizvi and Bhatnagar (2009) observed and analyzed the cell morphology of the microcellular foamed sample. Nebo *et al.* (2012) and Attia and Alcock (2009) used part mass as the output parameter to reflect the variability of the parts. All these characteristics relate to the particular parts. In order to focus on the molding process rather than the molded part, the curve measurement of the melt pressure was selected as the compared characteristic in the present work.

In order to improve the repeatability of the test result on the apparatus self-developed recently, the factors affecting the plastics injection molding process were investigated in this paper. The considered factors can be classified into two types: the traditional processing parameters and the test conditions. The latter one includes injection position, injection number and plasticization time. According to the experimental analysis, the operating procedure for injection molding tests was improved to ensure repeatability of the test result.

II. MATERIALS AND METHODS

An injection molding apparatus was recently established based on the capillary rheometer in our laboratory. It consists of a modified capillary rheometer (as shown in Fig. 1), a mold unit and a data acquisition system (as shown in Fig. 2). The operating procedure for injection molding can be concisely expressed as follows:

- First of all, the plastic sample is plasticized in the barrel with the temperature control module.
- Next, the mold clamping is implemented manually and easily with the slope structure of the mold boards.
- Thirdly, the mold is connected with the barrel by screwing down the nozzle.
- Then the sample would be filled into the mold cavity under the extrusion of the plunger rod.
- During the packing phase, the plunger rod moves down slowly.
- After cooling the molded part, the mold is manually opened, and one cycle for the plastics injection molding is completed. To carry out the next cycle of the experiments, we can start from the mold clamping phase.
- Additional, the data acquisition would be started in every cycle from the beginning of the filling phase

and stopped until the specified sampling time runs out.

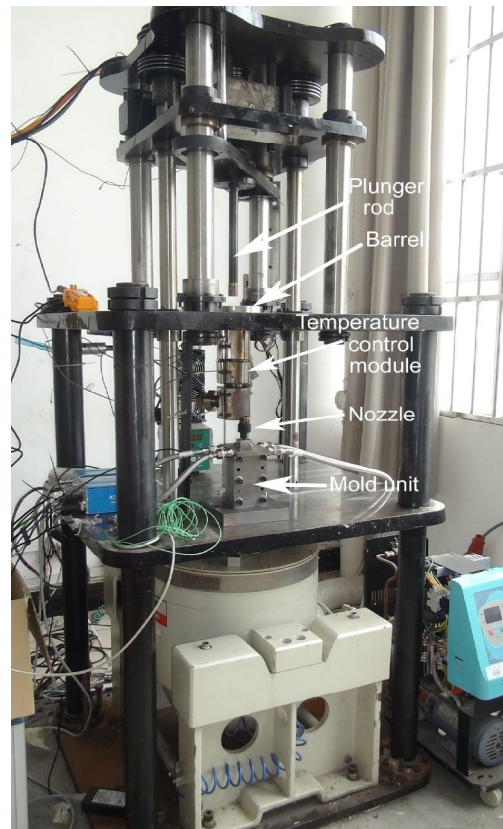


Fig. 1 Modified capillary rheometer

Fig. 2 shows the distribution of the measurement locations in the injection molding apparatus.

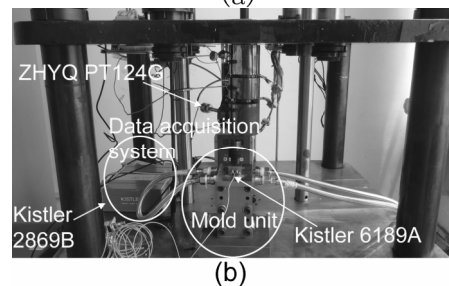
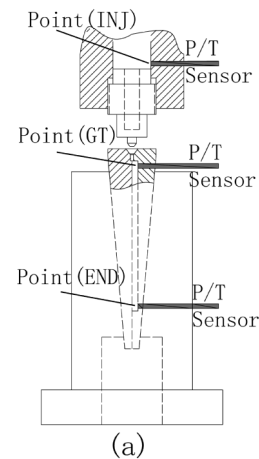


Fig. 2 Measurement locations: (a) schematic of the measurement distribution, (b) photo of the injection molding equipment

The sample pressures and temperatures in the mold cavity are monitored by the Kistler measuring system. The system includes a Kistler CoMo Injection (Kistler Instrument AG, type 2869B, Winterthur, Switzerland) for data acquisition, two combined pressure and temperature sensors (Kistler Instrument AG, type 6189A) for the detection of cavity pressure and sample contact temperature at the same position and a melt pressure and temperature sensor (Zhaohui Pressure Apparatus Co., type PT124G-131, Shanghai, China) for the measurement of the melt pressure and temperature in the barrel. As shown in Fig. 2 (a), the injection pressure P_{inj} and the injection temperature T_{inj} are acquired near the entrance to the nozzle at the bottom of the barrel, marked with the point INJ , by the sensor PT124G-131. The pressures of P_{gt} , P_{end} and the temperatures of T_{gt} , T_{end} in the mold cavity are measured by the sensors Kistler 6189A at the points GT and END respectively. And all signals of these sensors are parallel acquired by the injection process monitoring system Kistler 2869B to ensure the synchronization of the original data.

All experiments were performed with a common polymer of polypropylene (PP) T30S (supplied by Sinopec Maoming Co., with MFR 3.0 g/10 min, at 230 °C/2.16 kg).

An example of the experimental result, including the molded part and the measurement data, can be seen in Fig. 3.

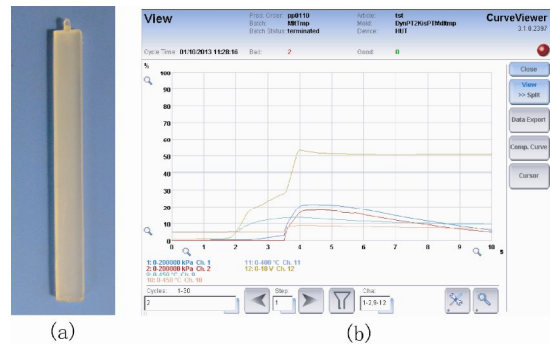


Fig. 3 Test result: (a) molded part, (b) measurement data

TABLE I
RANGE OF VALUE FOR EVERY FACTOR

Processing parameters	Range of value	Test conditions	Range of value
Barrel temperature (i.e. Melt temperature) /°C	180, 185, 190, 200, (210), 220	Plasticization time /s	11, (15), 42, 66
Mold temperature /°C	10, (20), 40, 60,	Injection position /mm	130, (180), 230
Injection speed /mm/s	80	Injection number /-	(1), 2, 3, 4, 5
Injection distance /mm	4, 6, (8), 10		
Packing speed / m/s	16, 18, 20, (22)		
Packing time /s	20, 40, (50), 60, 80		
	0, 3, 5, (7)		

To evaluate the effect of melt temperature on the injection molding of PP T30S, experiments were performed at melt temperatures of 155.8, 158.4, 162.3, 170.1, 178.1 and 186.2 °C (in practice, the controlled variable is the barrel temperature with the setting values of 180, 185, 190, 200, 210 and 220 °C). Meanwhile, all other factors (as shown in Table 1) remained unchanged. During the process of injection molding, melt pressures and temperatures were measured.

In the similar method, each factor was analyzed by varying its set value and keeping the other ones at the default value. All possible values of each factor are shown in Table 1, and the ones in brackets are the default. Because the driving motor of the test apparatus is the type of speed control, in this study the holding pressure of the traditional processing parameter was replaced by the moving speed of the plunger during the packing phase, namely packing speed.

III. RESULTS AND DISCUSSION

A. Effect of processing parameters

In order to check the effect of the melt temperature, the injection pressure P_{inj} acquired at the point INJ were measured as the functions of the time under different melt temperatures. As can be seen in Fig. 4 (a), the melt

temperature mainly influences the shape of the rising segment of P_{inj} curve. To describe the difference between these rising segments, the P_{inj} values of the inflection points are plotted versus the respective melt temperature as shown in Fig. 4 (b). In test range, the maximum (45.6 MPa at temperature of 155.8 °C) is almost 2.98 times of the minimum (15.3 MPa at temperature of 186.2 °C), and there is the difference of 198%.

Fig. 5 indicates that there were no significant differences in the injection pressure under various mold temperature. The difference between the maximum (51.6 MPa at mold temperature of 12.5 °C) and the minimum (45.5 MPa at mold temperature of 42.4 °C) is 13%.

The effect of injection speed on the injection pressure is shown in Fig. 6. Excluding the time difference, the injection pressure mainly varies during the packing phase under different injection speeds. It ranges from 38.1 MPa to 55 MPa, and there is the maximum difference of 44%.

The injection volume is denoted by the injection distance in this study. As can be seen from Fig. 7, P_{inj} reaches 44.5 MPa under the injection distance of 22 mm, while it decreases to 10.9 MPa under the injection distance of 16 mm. There is the difference of 308%.

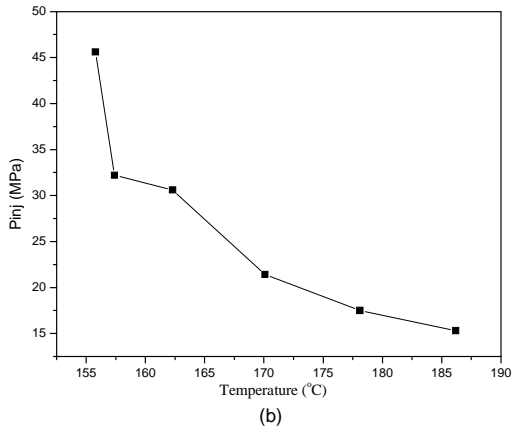
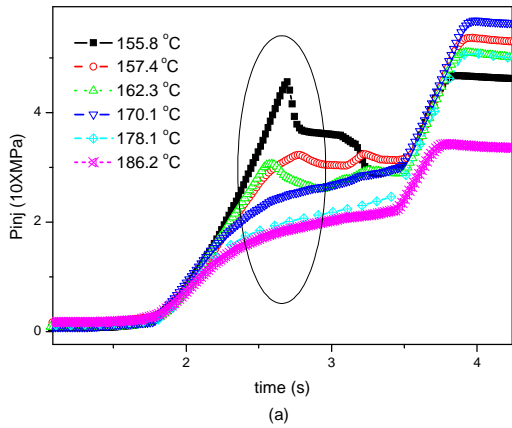


Fig. 4 Effect of melt temperature: (a) the injection pressure P_{inj} functions of the time under different melt temperatures, (b) P_{inj} values at the inflection points

The effects of packing speed and packing time are shown respectively in Figures 8 and 9. Both of them mainly affect the last segment of the P_{inj} curve. The variation of packing speed within the experiments induced the difference of 33%. And the packing time does not show clear effect on the P_{inj} value.

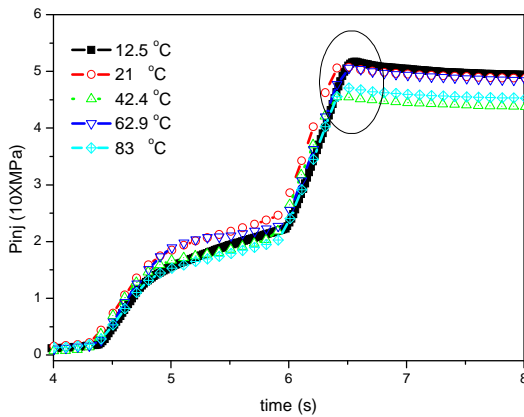


Fig. 5 Effect of mold temperature

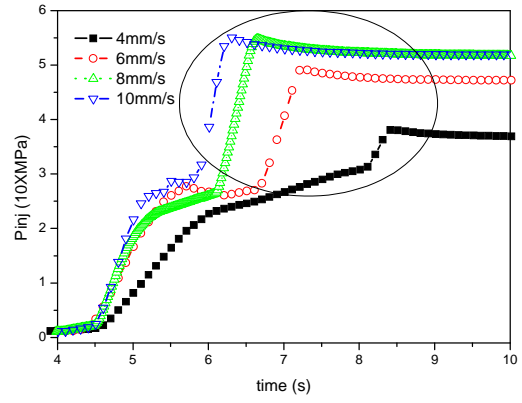


Fig. 6 Effect of injection speed

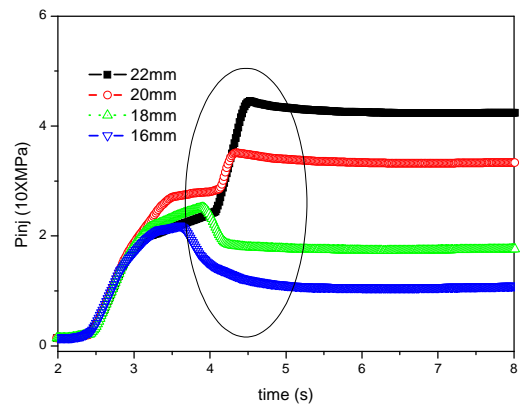


Fig. 7 Effect of injection distance

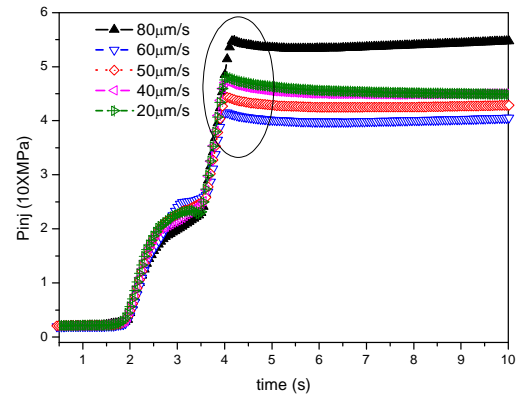


Fig. 8 Effect of packing speed

During the preliminary experiments, the test results couldn't coincide even if all processing parameters of the injection molding remain constant. Therefore, further experimental analysis was conducted to study the effect of test conditions on the repeatability of injection molding tests.

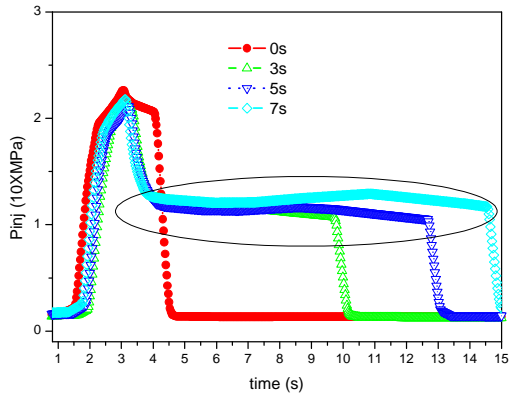


Fig. 9 Effect of packing time, under the special injection distance of 18 mm

B. Effect of test conditions

Considering the effect of plasticization time on the rheological properties of the polymeric melt, experiments were conducted under the plasticization time of 11, 15, 42 and 66 minutes. Fig. 10 shows that the plasticization time has slight effect on the injection pressure, and there is the maximum difference of 22% in the test range.

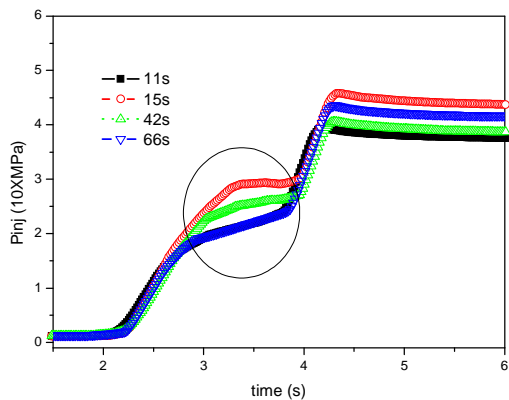


Fig. 10 Effect of plasticization time

The injection position is the displacement of the plunger with respect to the upper starting point. As the value of injection position increases, the plunger is closer to the nozzle at the bottom of the barrel, and the volume of the reservoir in the barrel is smaller. As shown in Fig.11, P_{inj} value at the inflection point increases from 31.9MPa to 81.8MPa when the injection position changes from 138 mm to 230 mm. The difference reaches 156%.

Because the volume of the reservoir in barrel is several times of the volume of the mold cavity (i.e. the sample volume), one barrel of polymeric melt could be used to perform several injection molding experiments. These experiments were numbered in accordance with their order of execution. Fig. 12 shows that the injection number is a significant factor for the injection molding process. P_{inj} value varied from 17.4 MPa to 73.2 MPa under different injections, and the maximum difference is 321%.

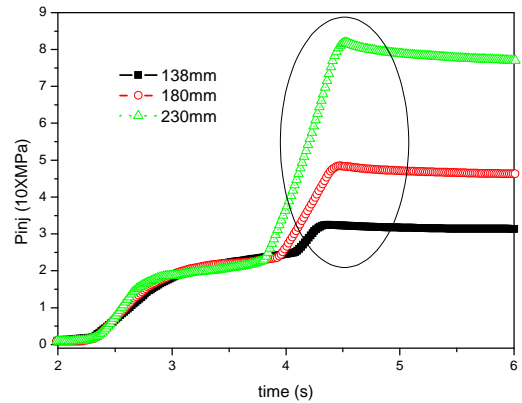


Fig. 11 Effect of injection position

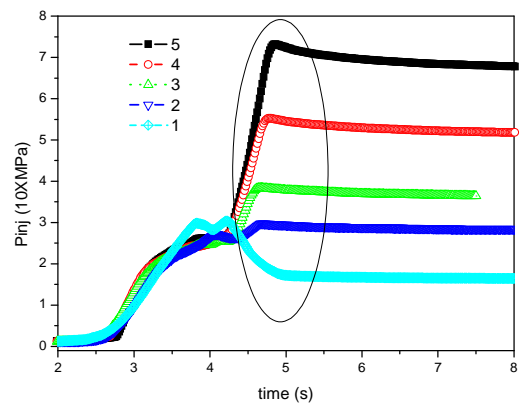


Fig. 12 Effect of injection number

IV. CONCLUSIONS

In summary, the injection distance is the key factor of the processing parameter affecting the injection pressure (P_{inj}) curve. The effect of the melt temperature is the second most important. On the other hand, within test conditions the injection number is by far the most important factor affecting the P_{inj} curve. And the injection position is slightly less important. Mold temperature, packing time and plasticization time do not show significant influence on the injection pressure in test range.

In order to ensure the repeatability of test result, the following operating precautions must be taken during the injection molding test on the self-developed apparatus:

- ✓ The injection distance (i.e. injection volume) should be precisely controlled.
- ✓ The injection molding could be conducted only once with one barrel of sample to avoid the change in melt density caused by the injection history.
- ✓ The plunger should start injecting at the same point, e.g. the injection position of 180 mm, which makes the sample in the barrel having a consistent volume and the same compressibility.

According to the experimental analysis, the coincidence of the injection molding test can be improved with these effective correcting measures.

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