

# Online Monitoring Rheological Property of Polymer Melt during Injection Molding

Chung-Chih Lin, Chien-Liang Wu

**Abstract**—The detection of the polymer melt state during manufacture process is regarded as an efficient way to control the molded part quality in advance. Online monitoring rheological property of polymer melt during processing procedure provides an approach to understand the melt state immediately. Rheological property reflects the polymer melt state at different processing parameters and is very important in injection molding process especially. An approach that demonstrates how to calculate rheological property of polymer melt through in-process measurement, using injection molding as an example, is proposed in this study. The system consists of two sensors and a data acquisition module can process the measured data, which are used for the calculation of rheological properties of polymer melt. The rheological properties of polymer melt discussed in this study include shear rate and viscosity which are investigated with respect to injection speed and melt temperature. The results show that the effect of injection speed on the rheological properties is apparent, especially for high melt temperature and should be considered for precision molding process.

**Keywords**—Injection molding, melt viscosity, shear rate, monitoring.

## I. INTRODUCTION

**I**NJECTION molding method provides an efficient way for mass production. Plastic product made by this method takes only little time and the shape of the part may be more complicated than that made by other methods. The cycle of an injection molding process starts from plastic material which is melted by the heat of the barrel of injection machine. Then, the melted material is injected into the mold cavity. As the cooling stage of injection process is over, the melted material inside the mold cavity becomes stiff enough for ejection. The molded part is ejected out of the mold cavity, and afterward, some inspections are implemented offline for quality verifications, such as dimensional accuracy, mechanical property performance, etc. Quality is a critical factor that affects the automatization of injection process [1]. If the molded product with unaccepted defect arises, it will lead to lots of wastes in material and high energy consumption. Besides the mold design and material property, the setting parameter in injection process is still an important factor which dominates the molded product quality.

As an initial setting of processing parameters is given, a stable process of injection molding is supposed to be

proceeded. In fact, some variations resulting from the machine characteristics or the environment temperature still influence the molded part quality. The quality fluctuations in the part cause the efficiency of automation decreased. Some researchers used pressure or temperature sensors to measure data directly in injection process and studied the molding conditions through investigating the change of pressure or temperature trace. Kurt et al. [2] studied the influence of cavity pressure on dimensional accuracy of parts in a four-cavity mold. They investigated the pressure trace of cavity in injection mold to determine the molding quality. Dlugas and Kountz [3] investigated different approaches on determining the optimal injection speed and found that plastic material injected in relative low viscosity can achieve a more accuracy quality of the molded part. The defects of molded part in their study were found after the part was taken out of the mold cavity. Gao et al. [4] studied molded part quality through in-process measurement. They correlated actual melt state (pressure, temperature, and melt flow velocity) with the dimensional accuracy of the molded part and concluded that the melt state in injection molding process was useful for the prediction of the quality of molded part.

The main goal of this work is to develop a method that can be used for online detection of the rheological property of polymer melt through in-process measurement. A test mold which contains a pressure sensor and a temperature sensor is prepared for the measurements. As the measured data are collected, the shear rate and the viscosity of polymer melt in injection process can be determined immediately through the apparatus developed in this work. After a series of injection shots with different setting parameters are tested, 3D plots representing the rheological properties with respect to injection speed and melt temperature are generated automatically. The proposed method transfers the measured data to the rheological information for better understanding and reveals the effect of processing parameters on the state of polymer melt. It can be used to determine a feasible processing window for plastic engineer.

## II. PROCESS INSTRUMENTATION

A schematic sketch and experimental setup used in this study are illustrated in Fig. 1. The rheological property of polymer melt provides further information to understand the influence of processing parameters on the melt state. A real-time calculation of rheological property of polymer melt during injection process can be performed on the apparatus.

Chung-Chih Lin is with the Dept. of Mech. and Computer-Aided Eng., National Formosa University, Taiwan (phone: 886-5-6315321; fax: 886-5-6315310; e-mail: lince@nfu.edu.tw).

Chieh-Liang Wu is with the Dept. of Mech. and Computer-Aided Eng., National Formosa University, Taiwan.

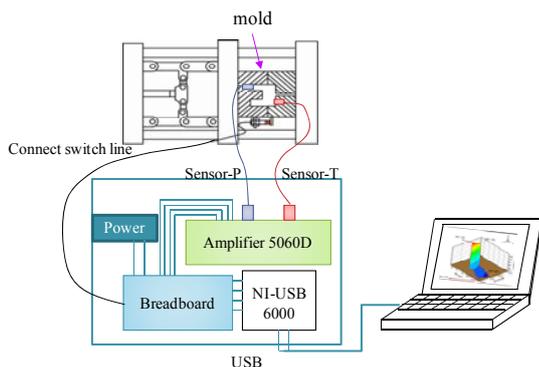


Fig. 1 A schematic arrangement of the experiment

### A. Principles

The flow behavior of plastic material in the filling stage of injection process is modeled as a Newtonian flow. A cavity is installed with a pressure sensor (Sensor-P) and a temperature sensor (Sensor-T), as shown in Fig. 2. The flow distance between both sensors and the corresponding filling time are  $L$  and  $t$  respectively. The flow speed  $v$  can be defined by

$$v = \frac{L}{t} \quad (1)$$

As the flow speed of the plastic melt is determined, the shear rate  $\dot{\gamma}$  can be determined by [5]

$$\dot{\gamma} = \frac{6v}{b} \quad (2)$$

in which  $b$  is the thickness of the flow path. The relative viscosity  $\eta_{rel}$  defines the effect of injection speed on the melt flow-ability and is determined by [5], [6]

$$\eta_{rel} = \Delta P t \quad (3)$$

where  $\Delta P$  is the pressure  $\Delta P$  for melt to flow. As the flow path geometry, the flow speed, and pressure difference along the path are determined, then the rheological properties including shear rate and the relative viscosity can be generated.

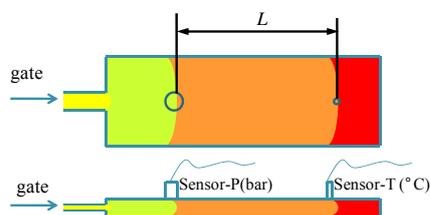


Fig. 2 The sketch of polymer melt flow into a cavity installed with a pressure sensor (Sensor-P) and a temperature sensor (Sensor-T)

When the polymer melt flows into the mold cavity as shown in Fig. 2, the corresponding signals from the sensors appear sequentially. A complete cycle of polymer melt injected into the mold cavity as well as the corresponding signals is

demonstrated in Fig. 3. With the increase of injection volume, the polymer melt passes by the Sensor-P at  $t_1$  and the pressure signal starts to appear. The temperature signal rises rapidly as the polymer melt arrives at Sensor-T. The moment of time  $t_2$  at which the temperature signal changes suddenly is defined as a SLP (Switch level point) [5]. The time difference  $\Delta t$  represents the flowing time for polymer melt passing by these two sensors and equals to  $(t_2 - t_1)$ . The pressure of Sensor-P at  $t_2$  equals to the pressure difference  $\Delta P$  and be regarded as the required pressure for the polymer melt to flow through these two sensors.

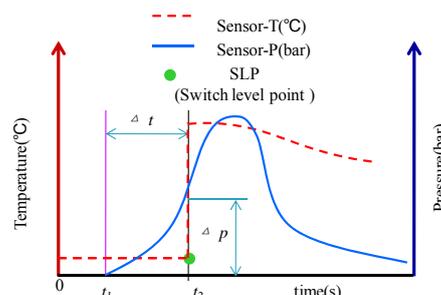


Fig. 3 Pressure and temperature signals for a complete cycle of injection molding

### B. Material

The plastic material used in this study was Polycarbonate (PC, PC-110, manufactured by Chi Mei Company). The processing temperature was suggested from 260°C to 320°C. The melt index (MI) for the resin is 10 g/10min (300°C, 1.2 kg). In order to reduce the moisture disturbance, a dehumidification was introduced before molding process.

### C. Cavity Geometry of Mold Design

The cavity of the mold was machined into two different sections, one for tensile test and the other for impact test, whose dimensions were designed according to ASTM-D638 and ASTM-D256, respectively. Note that the length of the specimen of impact test is twice the original length for a better balanced filling in injection process. Two sensors were used for experiment. Sensor-P (Priamus, 6001B) for pressure measurement was installed on the runner near the sprue of the mold and Sensor-T (Priamus, 4004B) for temperature measurement was installed in the cavity. The distance between both sensors was 174.6 mm as shown in Fig. 4.

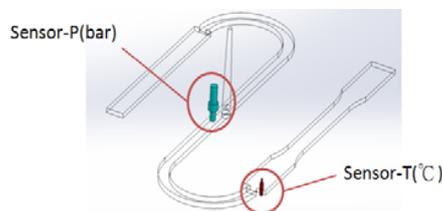


Fig. 4 Two sensors installed in the cavity

### D. Apparatus for Signal Processing

The signals of the two sensors were delivered to the charge amplifier (Priamus, 5060D) and transformed into voltage

output. A simple logic circuit for signal pre-processing was designed into the breadboard and then transferred to the data acquisition modulus (NI, USB-6000) for signal processing. The signal processing program was designed by using LabVIEW software. The sketch of the apparatus connecting to injection mold is illustrated in Fig. 5. The photo of the apparatus for signal processing is shown in Fig. 6. In injection molding process, the required signals were received and three rheological properties including shear rate and relative viscosity were processed by this apparatus.

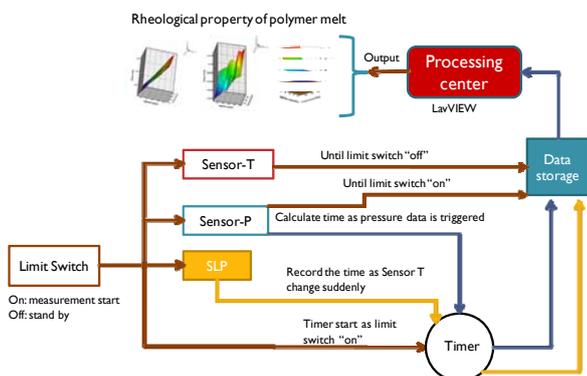


Fig. 5 A schematic expression of logic circuit of experiment

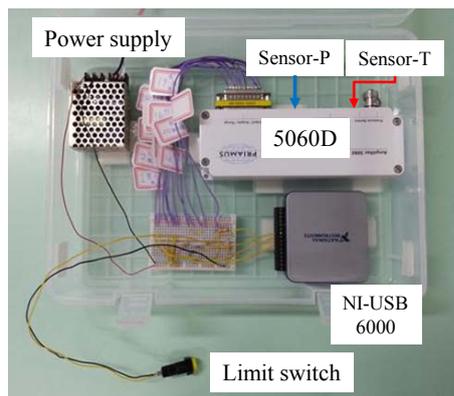


Fig. 6 The photo of the apparatus for signal processing

#### E. Molding Process

The injection machine used in this study was Fanuc Roboshot ( $\alpha$ -S50iA) and the speed setting was from 30 mm/sec to 300mm/sec with an increment of 30 mm/sec. Three melt temperatures, 250°C, 280°C, and 310°C were tested. A series of injection speeds from low to high with three melt temperatures were implemented to investigate the rheological property of polymer melt. The detailed setting parameters for the molding process are listed in Table I. The samples of the different injection speed setting are collected for 20 cycles after no apparent change of the molded part occurred.

#### F. Characterization

The rheological property of the molded part in molding process was calculated through the apparatus developed in this

study. In order to validation the accuracy of the result calculated by the proposed apparatus, a commercial equipment eDAQ (Priamus, 8102) for the signal processing unit were used for validation.

TABLE I  
PARAMETERS FOR MOLDING PROCESS

Parameter	Setting Range
injection pressure	30mm/sec~300mm/sec
suck back stroke	10 mm
holding pressure	20 bar
holding time	6.5 sec
melt temperature	250°C~310°C
injection stroke	4 sec
V/P switch point	6 mm

### III. RESULTS AND DISCUSSION

Since the molding parameters for injection machine are determined at the control panel, the polymer melt is supposed to be perfectly injected into the mold cavity in accordance with the parameters. In fact, the variation between the real melt state in the mold cavity and the setting parameter of the machine exists. The time for polymer filling into the cavity at melt temperature 280°C is illustrated in Fig. 7. The filling time for different injection speeds are supposed to be linear decreased with respect to the increase of the injection speed. However the measured data show a little deviation as the injection speed is over 250 mm/sec. It means that shear thinning behavior of polymer perform its importance at high injection speed. The results processed by eDAQ (Priamus, 8102) and the proposed apparatus are the same.

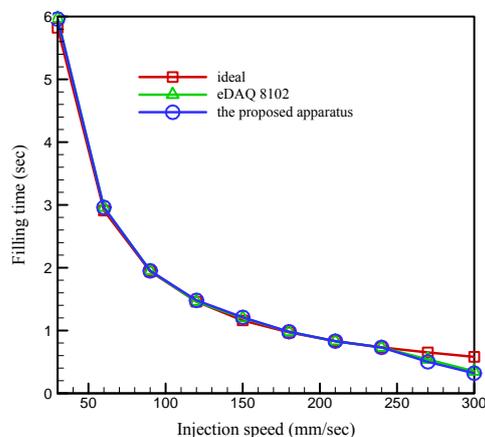


Fig. 7 The required time with respect to injection speed at different melt temperatures

The shear rates of polymer melt filling into the mold cavity with three melt temperatures are shown in Fig. 8. As the injection speed is over 200 mm/sec, the deviations among them become apparent. It means that the effect of high injection speed enhances the shear rate apparently for high melt temperature.

Fig. 9 shows the relative viscosity of polymer melt with

respect to injection speed and melt temperature. The relative viscosity bends to lower value as the injection speed is increased and tilts toward lower value as the melt temperature increases. This result conforms to the previous result as shown in Fig. 8. It reveals that a relative high injection speed or high melt temperature can reduce the viscosity. If polymer is processed in such condition, a stable quality of the molded part can be achieved easily [5]-[7].

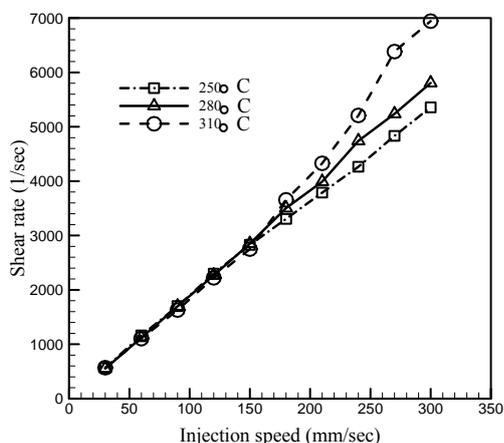


Fig. 8 The shear rate with respect to injection speed

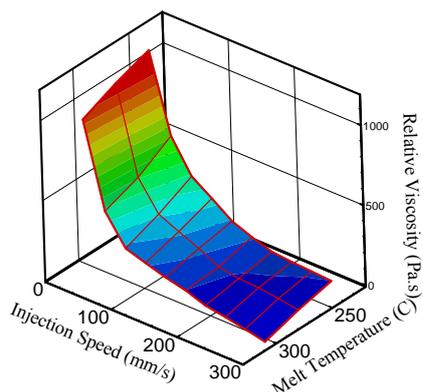


Fig. 9 The viscosity of polymer melt with respect to injection speed and melt temperature

#### IV. CONCLUSIONS

In this paper, an approach to online monitoring the rheological properties of polymer melt during injection molding is presented. It provides an alternative to understand the influence of processing parameters on the state of polymer melt. The apparatus developed in this work is validated with commercial equipment and provides the function of processing signals (pressure, temperature) into rheological data in time. The information shown on injection machine is limited, so that understanding rheological property is important for predicting the performance of molded part quality significantly.

#### ACKNOWLEDGMENT

The authors would like to thank for the financial support

from National Science Council in Republic of China under the contract number of MOST103-2221-E-150-015-.

#### REFERENCES

- [1] Robert X. Gao, X.Y. Tang, G. Gordon, and David O. Kazmer, "Online product quality monitoring through in-process measurement," *CIRP Annals -Manufacturing Technology*, to be in press.
- [2] M. Kurt, O. S. Kamber, Y. Kaynak, G. Atakok, and O. Girit, "Experimental investigation of plastic injection molding: Assessment of the effects of cavity pressure and mold temperature on the quality of the final products," *Materials and Design*, vol.113, pp.3217-3224, 2009.
- [3] D. M. Dlugas, and A. E. Kountz, "Investigation of differing approaches to determine an optimum injection velocity during mold filling," in ANTEC conference, Chicago, 2011, pp. 1627-1635.
- [4] Robert X. Gao, and David O. Kazmer, "Multivariate sensing and wireless data communication for process monitoring in RF-shielded environment," *CIRP Annals -Manufacturing Technology* vol. 61, pp. 523-526, 2012.
- [5] C. C. Lin and C. L. Wu, "Study Molded Part Quality of Plastic Injection Process by Melt Viscosity Evaluation," *Advances in Material Research*, vol.3, pp.327-339, 2014.
- [6] C. C. Lin, "Influence of injection velocity on quality of insert molding," *Polymer Engineering and Science*, vol. 52, pp. 268-276, 2012.
- [7] J. P. Beaumont, *Runner and gating design handbook: tools for successful injection molding*, 2nd ed. Hanser, Ohio, 2007.

**Dr. Chung-Chih Lin** worked at the Plastics Industry Development Center in the area of plastic products design for 13 years. He joined National Formosa University in 2010, where he is currently an associate professor. His interesting is in injection molding and mold design. He is also a member of SPE (Society of Plastics Engineering).

**Chien-Liang Wu** is a research assistant in National Formosa University.