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Online quality monitoring of molten resin in injection molding

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ABSTRACT

The quality of injection molded components is significantly dependent on the viscosity of the molten resin. Thus, in predicting and compensating for quality variations, it is essential that the resin viscosity be monitored in an online and automated manner. Accordingly, the present study proposes a method for evaluating the melt quality of the molten resin by means of three pressure sensors installed at the nozzle, runner and mold cavity, respectively. Four melt quality indexes are proposed based on the detected pressure signals, namely the pressure peak index, the viscosity index, the energy index and the pressure gradient. The validity of the proposed indexes is examined under various injection speeds, barrel temperatures and mold temperatures. It is shown that of the four indexes, the pressure peak index is the most strongly associated with the product quality; followed by the energy and viscosity indexes extracted from the nozzle and runner pressure signals. Overall, the results presented in this study show that the proposed monitoring system and quality indexes provide a convenient and effective means of monitoring shot-by-shot variations in the melt quality during continuous injection molding processes.

1. Introduction

With the advantages of a low cost and high efficiency, injection molding is one of the most common methods of mass production and is used extensively in the fabrication of automotive components, electronics, household items, optical lenses, sports goods, medical devices, and so on. However, while injection molding is an established technology with many decades of use, factors such as the processed raw material, the plasticizing quality and the processing parameters result in significant variations in the product quality. Traditionally, researchers have attempted to improve the quality of injection molded components by controlling the screw position, the injection and holding pressures, and the mold and barrel temperatures. However, many studies have shown that the geometrical dimensions of molded components still tend to vary quite significantly from shot to shot even when such controls are applied. In other words, further work is required to properly understand the factors affecting the melt quality of the molten resin in each cycle such that more effective control strategies can be put in place.

The plasticizing quality in the injection molding process is dependent on the shear rate, temperature and pressure during the plasticization stage, and is essentially manifested in the viscosity of the molten resin. The viscosity determines the flow behavior of the resin through the mold, and therefore has a significant effect on the quality of the molded components. As shown in Fig. 1, the viscosity of polymer melts is determined by three main factors, namely (1) the raw material, e.g., the type of material, the rheological characteristics of the material, the humidity conditions, and batch-by-batch variations; (2) the plasticizing effect, which is influenced by the geometrical design of the injection screw, the screw rotational speed, the back-pressure, the feeding rate, the barrel temperature and the metering time; and (3) the injection parameter settings, e.g., the injection speed, the mold temperature, the melt temperature, the pressure, and the cooling time. Traditionally, the plasticizing process is performed using a reciprocating single screw that conveys, melts and meters the molten resin at a constant rotational speed. However, significant variations in the plasticizing quality are often observed, even when the screw motion is precisely controlled. Amano and Utsugi [1–3] investigated the effects of the processing parameters on the temperature distribution of the molten resin in the barrel and found that the plasticizing quality of the molten resin was determined mainly by shear heating and heat absorption effects. It was shown that the shear heating effect was related to the shear rate and screw rotational speed in the metering zone, while the heat absorption effect was dependent on the residence times in the feeding and compression zones, respectively. Accordingly, the authors suggested the use of a long metering zone such that the raw materials

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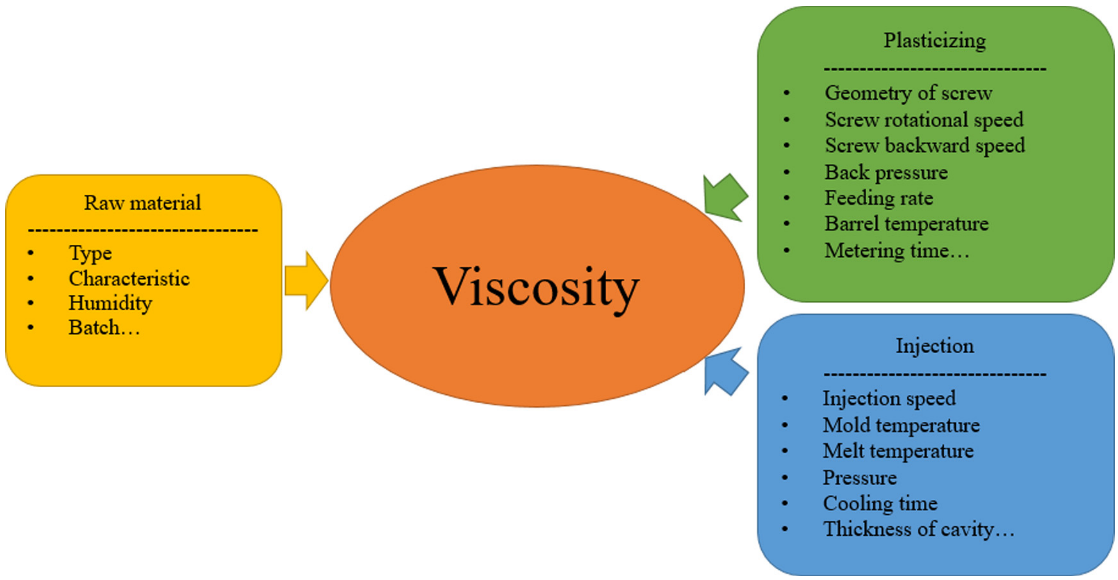

Fig. 1. Factors affecting viscosity of molten resin.

were sufficiently heated prior to entering the feeding and compression zones. Jin et al. [4] investigated the behavior of solid-bed breakage and observed that the break-up of the solid-bed seriously degrades the quality of injection-molded parts. Consequently, a properly designed barrier screw, and an appropriate processing parameter setup, are essential in improving the quality and consistency of the finished components.

Modern electric injection units provide excellent accuracy and repeatability in the injection molding process. However, controlling the transient and distributed states of the molten resin still presents a significant challenge [5,6]. The quality of injection molded components is governed by four main factors, namely the melt temperature, the pressure, the injection velocity and the apparent viscosity. The viscosity uniformity of the molten resin, in particular, has a significant effect on the geometrical accuracy and mechanical properties of the finished components. In practice, changes in the flow ability (i.e., viscosity) of the molten resin result in an inconsistent flow behavior as the resin enters the mold cavity. The resulting variable pressure drop along the flow path potentially generates different levels of shrinkage, and may therefore result in part warpage [7,8].

In the injection molding process, the pvT (pressure, specific volume, and temperature) diagram describes the dependence of the specific volume of the molten resin on the pressure and temperature. The quality of injection molded parts is governed almost entirely by the pressure and temperature processing conditions. As a result, pvT- based process control has long been used to improve the process capability. In practice, realizing online temperature control is extremely challenging since polymer is a low heat-conductivity material. Thus, most modern control strategies focus on the pressure process variable. Michaeli and Shreiber [9] proposed a process-variable based control method in which the cavity pressure in the holding phase was dynamically adjusted online in such a way as to minimize the effects of changes in the mold and melt temperatures on the molded part weight. Wang and Mao [10] proposed a similar pvT-based method for adjusting the injection pressure in accordance with changes in the mold temperature so as to maintain a constant part volume or part weight. Hopmann and Reßmann [11] presented a method for compensating for the effects of viscosity changes on the volumetric shrinkage of injection molded components by adaptively adjusting the injection speed such that the measured pressure profile was driven continuously toward a predetermined reference profile. Heinzler et al. [12] proposed a technique for compensating for the effects of process variations such as the raw material moisture content on the quality of injection molded components by means of a pressure control strategy during the injection phase combined with a control of the switch-over point and packing pressure.

The melt viscosity in injection molding processes is traditionally measured using a viscosity rheometer. However, the measurement process is performed off-line, and hence the results, while useful for post-manufacturing analysis purposes, are of no help in turning the processing parameters during the molding process itself. Accordingly, Gornik [13] developed an online viscosity measurement method in which the melt viscosity was determined based on a 10-min measurement of the melt flow rate under specific temperature and pressure conditions by pressure and temperature sensors installed in the nozzle of the injection molding machine. The author also proposed a torque rheometer for obtaining online measurements of the melt viscosity in the plasticizing process based on the principle that the energy consumed during plasticization is theoretically proportional to the melt volume in each shot. Aho and Syrjälä [14] detected changes in the viscosity of the polymer melt during continuous injection molding by means of a slit die equipped with pressure sensors. Zhang et al. [15] showed that the melt viscosity is proportional to the ratio of the pressure gradient to the volumetric flow rate, and can be used to compare the homogeneities of molten resins injected using different screw configurations. Kruppa et al. [16] presented a method for improving the consistency of injection molded parts by adjusting the mold temperature in accordance with changes in the nozzle pressure, as detected by pressure sensors installed within a rheometer nozzle. Combining apparent viscosity, melt temperature, and melt pressure, a significant determination of melt quality can be obtained. Asadizanjani et al. [17] presented a method for obtaining online estimates of the melt viscosity using the pressure, temperature and velocity measurements acquired using a multivariate sensor consisting of an IR detector and a piezoelectric sensor. Gordon et al. [18] proposed a similar online viscosity measurement system based on simultaneous measurements of the cavity pressure, temperature and melt flow velocity, respectively. Gallo and Montgomery [19] presented an approach for