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A novel clamping force searching method based on sensing tie-bar elongation for injection molding

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ABSTRACT

Clamping force greatly influences the injection molding quality, particularly in molding thin-walled plastic parts. Low clamping on mold halves can easily cause flash defects in the part geometry, whereas high clamping can cause poor air venting that in turn causes a short shot. Therefore, using an optimal clamping force setting is crucial. However, traditional methods for estimating the clamping force for injection molding mainly use the total projected area of the cavity, sprue, and runner along the clamping direction multiplied with the predictive cavity pressure of a molten polymer. Because this prediction is rough, a maximal machine specification is commonly applied during practical operations. Thus, heavy loading on the machine and mold may generate defects on molded parts, cause extra energy consumption, and shorten the tool life. A strain sensor mounted on the tie bar can reveal the dynamics of the clamping force during injection molding. For example, tie-bar elongation increases during mold filling and packing when the high-pressure molten polymer acts on the mold halves. This study developed a novel searching algorithm based on information about tie-bar elongation with various clamping force settings to identify the proper clamping force value to set. An experimental verification shows that the clamping force determined using the proposed method feasibly improves the injection molding quality.

1. Introduction

Injection molding is a cyclic process that consists of four phases: filling, melt compressing (or packing), holding, and cooling. As shown by the typical cavity pressure profile in Fig. 1, the pattern from Points A to C represents the filling stage, in which a molten polymer enters the mold cavities, following which the cavity pressure is gradually increased according to the applied injection pressure. The filling phase is completed at Point C, where the cavity is only volumetrically filled by the molten polymer without being compressed. The packing process then starts, and the pressure increases rapidly to its peak value (*Pmax*) at Point D, which has the greatest effect on the resisting mold clamping force introduced by the clamping mechanism in the whole injection molding process. The molten polymer within the cavity is then maintained at a set pressure during the holding phase. Additional molten polymer can be packed into the cavity to compensate for plastic shrinkage caused by cooling, thus ensuring that the mold is completely filled. This process continues until the gate is frozen, as marked at Point E. This is followed by the final cooling phase, and it continues until the end of the cycle. During this phase, the melt solidifies gradually as the coolant that circulates within the cooling channels in the mold removes heat. The cooling and solidification rates determine the rate at which the cavity pressure decreases [1].

The main parameters influencing the quality of injection-molded parts include the injection speed, melt and mold temperatures, filling–packing switchover, packing pressure and time, and extent of mold separation at various clamping force values [2–4]. In particular, mold separation occurs as excessive force is applied on the mold walls because of the high cavity pressure at the end of the filling, which momentarily exceeds the operating clamping force. This situation is often serious when high injection pressure is required in a thin-walled molding [5–8]. The invisible mold separation that elongates the tie bars of the injection molding machine may cause flash defects, resulting in inconsistent part weight and thickness. Additionally, asymmetric mold separation may dramatically increase the damage caused to the mold and reduce its lifetime.

Previous studies have revealed that cavity pressure is strongly associated with the degree of mold separation in injection molding, and these factors determine the part quality. For instance, Chen et al. [9] installed linear variable differential transformer sensors on each corner of mold halves to detect their displacement and

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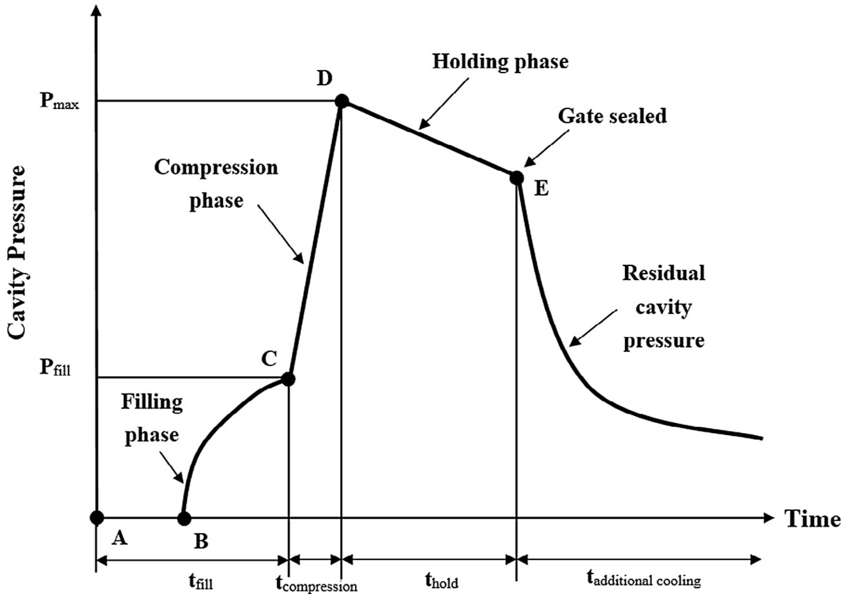

Fig. 1. Typical cavity pressure profile.

found that mold separation is positively correlated with part weight. To isolate the injection molding quality from the change in mold and plastic materials, they built an adaptive controller to detect adequate velocity/pressure switchover timing on the basis of mold separation. The injection molding quality can be predicted by monitoring the mold separation, which is strongly correlated with cavity pressure [10]. Fei et al. [11] studied the optimization of process parameters by using a neural network and genetic algorithm and concluded that the warpage of injection-molded parts depends on the clamping force. Satoshi et al. [12] found that the volumetric shrinkage of parts is associated with the clamping force and suggested that high injection and holding pressures combined with high clamping force are beneficial for achieving a minimal shrinkage rate.

To prevent mold separation during mold filling and packing, mold clamping is typically performed at the maximum specification of the mold-clamping mechanism that achieves secure clamping without the occurrence of defects such as flash. However, with the application of excessive mold clamping force to the mold, mold deterioration is accelerated and energy consumption is increased unnecessarily. Moreover, such excessive clamping force settings stain and damage the surfaces of mold cavities, and insufficient gas venting leads to the formation of weld lines, burns, and black streaks. By contrast, clamping a mold with the required minimum clamping force, that is, the proper clamping force, can extend the mold life, reduce energy consumption, and prevent the occurrence of defects in injection-molded parts [13–15].

The conventional prediction of the minimal clamping force for preventing the mold from opening during injection is based on the estimation of the applied injection pressure for injecting a specific molten polymer into a mold cavity multiplied with the projected area of the part and sprue-runner-gate system along the clamping direction. This calculation is rough, and it neglects the increase in the clamping force required resulting from the asymmetric layout of the cavity and gates. Most people setting the magnitude of the clamping force on the controller choose the maximum specification permitted by the injection molding machine. This habit causes a venting problem that may generate short shots and increase the damage to mechanical components of the toggle clamping unit that, in particular, causes tie-bar breakage. Using a high clamping force in an injection mold shortens its lifetime.

Currently, press-on strain sensors on tie bars are used for measuring the surface strain directly at the mounting location, in a manner similar to bonded strain gauges such as tie-bar strain sensors can be used to measure the clamping force. The strain gauges are pressed under a stainless steel protective foil wrapped tightly on the cylindrical surface of the tie bar to be measured.

$$\varepsilon_i = \frac{F_i}{EA} \tag{1}$$

$$F_i = \frac{EA\varepsilon_i \times 10^9}{9.81} \tag{2}$$

$$F = \sum_{i=1}^{n} F_i \tag{3}$$

where ε_i is the stress of the ith tie bar in micrometers, E is Young's modulus of the tie bar (=210,000 kgf/cm^2), A is the cross-sectional area of a single tie bar in squared millimeters, F_i and F respectively represent the ith tie bar and the total clamping force in tons, and n is the number of tie bars.

On the basis of an accurate measurement of the clamping force acting on mold halves during injection molding with tie-bar strain sensors, an injection molding machine can detect the variation of tie-bar elongation online. The minimal clamping force for achieving high injection quality with low energy consumption and machine and mold damage can be precisely estimated easily. This study proposes an intelligent clamping force searching method that quickly and precisely suggests a proper clamping force setting value. Various experimental case studies verify the feasibility of this method.

2. Status of mold separation

Fig. 2 shows three mold conditions with different clamping force settings during injection molding: S1, S2, and S3. S1 is a state in which even upon a reduction in the clamping force setting, the largest increment in the applied clamping force does not change during the interval. In this state, because the clamping force with respect to the injection pressure is sufficiently high, the mold is compressed; that is, the mold height between the movable and