Precision Engineering xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Precision Engineering

journal homepage: www.elsevier.com/locate/precision

Influence of clamping force on tie-bar elongation, mold separation, and part dimensions in injection molding

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ARTICLE INFO

Keywords:
Clamping force
Flash
Injection molding
Mold separation
Tie-bar elongation

ABSTRACT

In injection molding, the magnitude of clamping force may affect the quality of plastic parts. A small clamping force may produce defects such as flashes and poor geometrical accuracy, whereas a large force could result in insufficient air venting during mold filling/packing, leading to the generation of short shot. Traditionally, clamping force is set at the highest machine specification, which may lead to additional energy consumption. Moreover, heavy loading at the tie bars is detrimental to the durability of processed molds and the machine itself. In this study, we developed a measuring system for recording tie-bar elongation and mold separation during injection molding at each corner of the mold. To determine the consequences of proper and improper clamping force settings on the quality of injection-molded parts, we systematically evaluated the effects of relevant parameters such as cavity layout and gate location on cavity pressure distribution during packing and the reactive force from cavity pressure acting on mold walls. Correlation analysis on experimental results depicted that the maximum increase in tie bar elongation and the maximum mold separation during injection molding are highly correlated with the thickness of plastic parts, and we suggested that the two features are good indicators of part quality. Moreover, cavity layout of generating diverse filling patterns and the distribution of cavity pressure is influential to mold separation as well as tie-bar elongation during mold filling. This phenomenon is further change the degree of mold separation at each corner of the injection mold and should be concerned in practice.

1. Introduction

Injection molding is used widely to mass produce plastic parts in many industries. The process comprises the following main stages: filling, packing, holding, cooling, and ejecting. In the filling stage, molten polymer flows through nozzle, runner, gate, and finally fills up the mold cavity with constant volumetric flow rate. Meanwhile, in-mold cavity pressure rapidly grows corresponding to the flow resistance of molten resin filling from nozzle to cavity. Further, the integral value of pressure along cavity volume projected to parting plane. Additionally, the male and female mold plates undergo the maximum mold separation attributed to the action of the molten polymer's maximum cavity pressure on the mold cavity. During holding, the molten polymer is compressed under constant pressure in hydraulic system to compensate for the reduction in specific volume because of cooling. Notably, the compensation resulting from holding pressure occurs only when the molten polymer at the gates is not frozen. In the cooling stage, the pressure decreases continually with volumetric shrinkage. Meanwhile, the injection screw is rotated to prepare polymer melt for the following cycle. Finally, the plastic parts are ejected from mold cavities and then cooled to room temperature under atmospheric pressure [1,2].

The relevant parameters influencing the quality of injection-molded parts include injection speed, melt and mold temperatures, filling–packing switchover, packing pressure, and the extent of mold separation under various clamping force settings [3,4]. Particularly, mold separation occurs caused by the exertion of excess force on the mold walls because of high cavity pressure at the end of the filling, which momentarily exceeds the operating clamping force. This situation is often serious in molding thin-walled parts, where high injection pressure is required [5]. The invisible mold separation that elongates the tie bars of an injection molding machine may lead to flash defects, resulting in inconsistent part weight and thickness [6].

Mold separation can be detected using a linear variable

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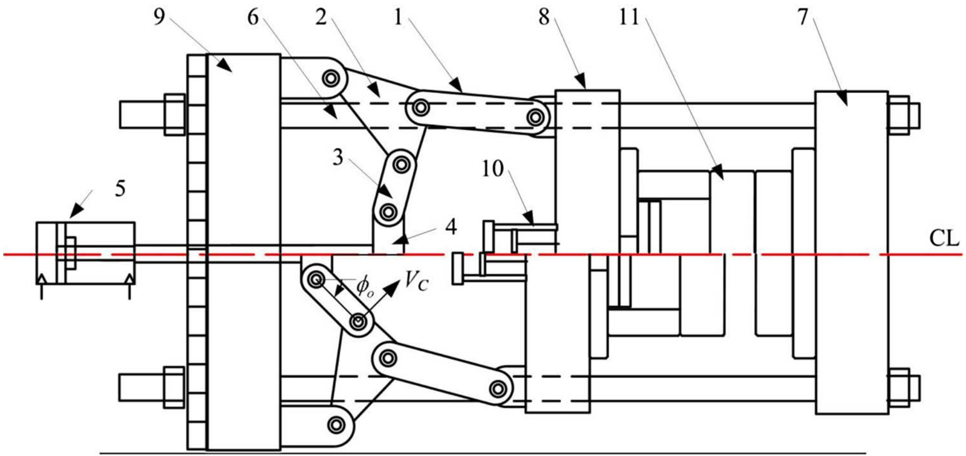
https://doi.org/10.1016/j.precisioneng.2017.11.007
Received 21 September 2017; Received in revised form 1 November 2017; Accepted 8 November 2017
0141-6359/



Item	Name	Item	Name
1	Moving platen side link	7	Stationary platen
2	Rear platen side link	8	Moving platen
3	Cross head link	9	Rear platen
4	Cross head	10	Ejection mechanism
5	Clamping actuator	11	Injection mold
6	Tie bar	CL	Central line

Fig. 1. Structure of a typical toggle-type clamping mechanism [11].

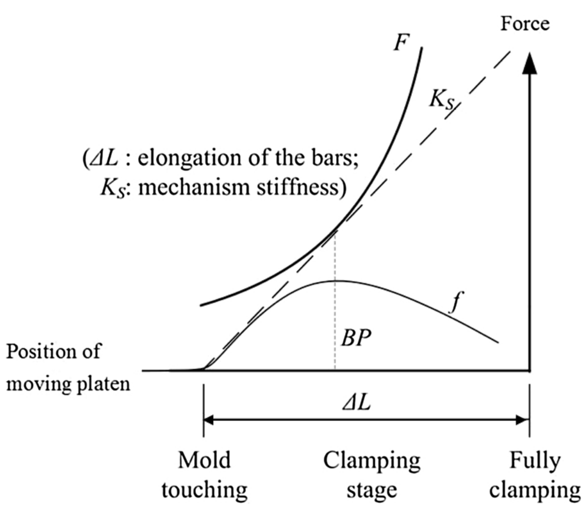


Fig. 2. Clamping force as a function of tie-bar elongation [11].

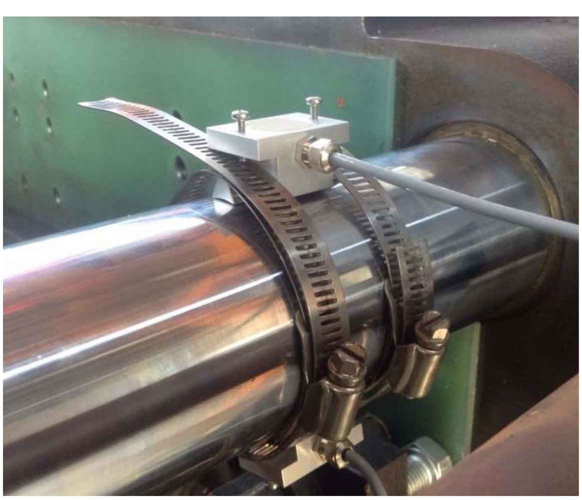


Fig. 3. Tie bar strain sensor.

displacement transducer, and it is associated with the above-mentioned major process parameters that affect injection molding qualities. Mold separation increases with decreasing clamping force and increasing melt and mold temperatures, resulting in an increase in part weight. Similarly, when packing pressure and injection speed increase, mold separation decreases. Early switchover from filling to packing can result in decreased mold separation and part weight. Packing pressure greatly influences mold separation, and the associated part weight varies [7].

To prevent a fateful mold separation that affects part qualities, a sufficient clamping force acting on the mold halves is applied. However, conventional prediction of the minimal clamping force for preventing the mold from opening during injection relies 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. To prevent mold separation during mold filling and packing, mold clamping is typically performed at the maximum pressure of the mold-clamping mechanism to achieve secure clamping without the occurrence of defects such as flash. However, with excessive clamping force, mold deterioration is accelerated and energy consumption is increased unnecessarily. Moreover, excessive clamping force settings stain and damage the surfaces of mold cavities, whereas 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, optimal clamping force, can extend mold life, reduce energy consumption, and avoid the occurrence of defects in injection-molded parts [8–10].

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. 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 estimation of minimal clamping force for achieving high injection quality with low energy