Design and Process Optimization of Polymer Filling for Electronic Key Shell Based on Numerical Analysis

Ji-Mei NIU
Guangzhou College of South China University of Technology, Guangzhou 510800, China
jimeiniu@163.com

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Abstract. The electronic key is widely used in our life due to its small volume, tempting color, beautiful shape and easily portability. In order to shorten the design cycle and reduce the test cost of mold for the shells of electronic key, the work should be done firstly to analyze the injection technique. The electronic key shell is analyzed by using Finite Element Method (FEM) to judge reliability of the structure. Static structural and explicit dynamics analysis are conducted. The results provide valuable reference for the structural optimization design. Injection moulding process of the shell is simulated by applying Moldflow. Results show that the shrinkage is too small, the average value 0.12 mm and maximum value 0.497mm, to neglect the negative effect on forming parts after the injection. Furthermore, the designed mold structure was reasonable, which meet the demand of injection practically.

Introduction

With the development of society, the plastic products are widely used. In fact, injection molding is becoming the most popular method for the cost-effective mass production of polymer products [1]. It has many advantages, such as short cycle time, good replication quality, and process automation. The mould structure might have a great influence on the quality of products because in the moulding process, because the mould will generate deformation due to thermal and pressure load, which in turn affect the mould and product precision[2]. In fact, it is relate to the melt flow in mould, temperature distribution, stress concentration, and so on. Injection molding have three principal steps, including filling, packing, and cooling of the polymer [3]. Every step directly affects the quality of the molded part. The traditional mould design based on the designer experience is very difficult to design the injection mould with the high quality. In this paper, the flow behavior of the molten polymer was investigated using Finit Element Method (FEM)[4], which can help designer find and eliminate the cause of short shot, weld line, and non-uniform filling, often occurring during the manufacturing process. The flow pattern and temperature distribution of the polymer were simulated to predict the incomplete filling during mold filling. Thus, the mould structures are improved. Furthermore, it also provides the method to improve the efficiency of designing about similar products.

Analysis Procedure

We focused our study of injection molding process on the shells of electronic key. It is asked to have some wear resistance and hardness using ABS plastic with thickness range from 1.5 to 5
mm, suit to use injection molding processing. And the electronic key shell of the thickest place for 5 mm. The 3D model and CAD drawing are shown in Fig.1. In the Moldflow software, there are three major mesh types, including Mid-plane, 3D and Fusion. Due to the average thickness of the shell is small, it makes the surface meshes (Fusion) as mesh type. The model parameters are including, die surface temperature for 45°C, melt temperature for 240°C, the default settings as others parameters.

![Figure 1. The CAD Drawing and 3D Model of Electronic Key Shell.](image)

In order to improve the production efficiency, we try to find optimal gate location in injection molding process for thin walled products. In this paper, due to the small size of plastic parts, we set the molds with four cavities, as shown in Fig.2.

![Figure 2. The Schematic Diagram of Molds with Four Cavities.](image)

In numerical analysis, a numerical model was built to simulate the injection molding process. The flow behavior of a molten polymer can be characterized as non-Newtonian, non-isothermal, incompressible flow for the filling of a mold cavity[5, 6]. The numerical analysis of injection molding process for the electronic key shell are governed by conservation equations of continuity, momentum, and energy. The governing equations are given by equations (1), (2), and (3). These can be solved by applying a thermodynamic state relation and boundary conditions.

\[
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = 0
\]  

(1)
\[ \rho \frac{\partial \vec{V}}{\partial t} = \rho g - \nabla p + \eta \nabla^2 \vec{V} \]  \hspace{1cm} (2)

\[ \rho C_p \frac{\partial T}{\partial t} = \nabla \cdot (k \nabla T) + \eta \gamma^2 \]  \hspace{1cm} (3)

where \( \rho, \ C_p, \ k, \ \eta, \ \text{and} \ \gamma \) are the density, specific heat, thermal conductivity, viscosity, and shear rate of the polymer, respectively. Process variables \( p, \ T, \ \text{and} \ V \) are the pressure, temperature, and velocity of the flow. The viscosity of molten polymer can be described by the modified-cross model of Williams–Landel–Ferry (WLF) equation defined as follows\[7\]:

\[ \eta_0 = D_1 \exp \left( \frac{-A_1(T - T^*)}{A_2 + (T - T^*)} \right) \]

\[ T^* = D_2 + D_3 p \]

\[ \eta = \frac{\eta_0}{1 + (\eta_0 \gamma^*)^{(1-n)}} \]

Here, \( D_1, D_2, D_3, A_1, \ \text{and} \ A_2 \) are data-fitted coefficients, and \( n \) is index of power-law, \( \tau^* \) is stress in transient area between Newtonian flow and power-law, \( \eta_0 \) is the zero shear rate viscosity.

**Results and Discussion**

For the thin walled products, the short shot often occurs when the polymer cannot fill the entire mold cavity. The time of filling begin from the melt flow into the cavity. The melt flow behavior was simulated using Moldflow, which can predict the filling behavior of plastic materials at any time. Fig.3 shows the average temperature of the thin walled products at ejection. It is clear that schemes are filled well, with no short shoot phenomenon. The average temperature of the thin walled product range from 30\(^\circ\)C to 80\(^\circ\)C while the max temperature of 83.2\(^\circ\)C are located around the pouring gate, which indicate the temperature distribution is very uniform on the whole shell of electronic key.
Fig. 4 shows the pressure distribution of plastic product. It is clear that the pressure of the thin walled product is within 0~1Mpa, which indicate the pressure distribution is homogeneous on the whole shell of electronic key. Fig.5 shows the volume shrinkage. It is all known that if the shrinkage is uniform throughout the part, the molding will not deform or warp, but only become smaller. In fact, the warpage is a distortion which might make the surfaces of the molded part deviate the designing. However, achieving low and uniform shrinkage is a complicated task, due to the presence and interaction of many factors such as molecular and fiber orientations, mold cooling, part and mold designs, and process conditions[8]. The mold shrinkage values, as shown in Fig.5, range from 0.18% to 6.59% for this plastic product, where the peak value of shrinkage of 6.59% are presented around the pouring gate.

Fig. 6 presents the results of warpage analysis given the recommended process parameters. The amount of warpage measures 3.44 mm, and the extent of warpage measures 0.5 mm, which is relatively small. Therefore, the extent of warpage on parts can be reduced by optimizing the parameters to improve the process of plastic injection mold packing.

### Conclusion

The plastic parts molding of electronic key shell was designed using Pro/E. Finite element analysis provides an effective means for analyzing the mold deflection, while requiring little capital investment. It aims to homogenize the temperature and reduce the warpage. In fact, the
further research is required to make experimental verification. The simulation results show that the average temperature of the thin walled product is within 30°C and 80°C at ejection. The values of mold shrinkage are between 0.18% to 6.59% for this plastic product. And filling speed is faster, the longest of the fill time was 1.8 s. Due to have more than one water channel, the volumetric shrinkage was homogeneous. Therefore, the results show that the injection molding situation for electronic key shell is very well by numerical simulation and can be used to all high precision molding applications.

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