# The Simulation and Optimization of Aspheric Plastic Lens Injection Molding

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**Abstract**: *For the purpose of reducing the volumetric shrinkage and volumetric shrinkage variation, the process in injection molding of aspheric plastic lens was simulated, and several process parameters which include holding pressure, melt temperature, mold temperature, fill time, holding pressure time and cooling time were optimized by using an orthogonal experimental design method. Finally, the optimum process parameters and the influence degree of process parameters on the average volumetric shrinkage and the volumetric shrinkage variation are obtained.*

**Key words**: *injection molding*; *volumetric shrinkage*; *volumetric shrinkage variation*; *orthogonal experimental design*

## 1 Introduction

Aspheric plastic lens was often used in precision optical apparatus which require manufactural tolerance at the range of several microns, so the control of lens' warpage is very important for injection molding of lens. Volumetric shrinkage and its distribution are important factors affected the warpage of the lens. However, process conditions, such as holding pressure, injecting speed and *etc*, can affect the volumetric shrinkage of products directly[1]. Jansen *et al*[2] had analyzed the influence of process conditions on shrinkage of seven thermoplastic plastics, and it showed that holding pressure and melt temperature have more obvious effect on the shrinkage of these seven materials and also have the same effect trend, but injection speed and mold temperature have slight effect and have no a consistency. Chang[3] had investigated the influence of process conditions on the shrinkage of three plastics in injection molding process by means of the Taguchi method. The investigation results indicated that mold temperature, melt temperature, holding pressure and holding time have prominent influence on the shrinkage of these three plastics. Huang and Tai[4] had studied the influence of process conditions on warpage of thin shell object in its injection molding process, too. Their research results pointed out that holding pressure has most significant influence on warpage, mold temperature, melt temperature and holding time take the second place, and the shape of injection gate and fill time had little influence. Lu and Khim[5] had analyzed the influence of different process conditions on the profile of optical lens, which is made of polycarbonate by the statistical experiment method, and it was concluded that mold temperature has the most influence on the profile of optical lens. All of the above research works indicate that the significant factor is different for different plastic materials in injection molding process. As a result, the optimization of process conditions is necessary for the design of process of lens injection molding[6-8].

## 2 Process Simulation

### 2.1 Model and materials

The dimension of the mold is shown In Fig.1. The finite model of fusion was built shown in Fig.2, in which there are 6257 elements. Coolant is pure water whose temperature is 25 ℃, and was controlled by specifying Reynolds number (that is 10000). CRYLICS (PMMA) produced by Mitsubishi Group, was selected as the material of the lens.

### 2.2 Process parameters in injection molding

For the purpose of attaining the volumetric shrinkage and its distribution, the filling, packing and cooling processes of the injection molding process of the aspheric plastic optical lens were simulated[9]. Additionally, in order to compare the difference of the volumetric shrinkage and its distribution obtained by using the different process parameters, two cases were simulated, and their process parameters are shown in Table 1.

**Table 1 The process parameters of the two cases**

| | Case 1 | Case 2 | | Case 1 | Case 2 |
|---|---|---|---|---|---|
| Fill Time/s | 1 | 0.2 | Cooling Time/s | 8 | 6 |
| Holding Pressure/MPa | 35 | 20 | Melt Temperature/℃ | 230 | 230 |
| Holding Pressure Time/s | 7 | 3 | Mold Temperature/℃ | 90 | 50 |

### 2.3 Numerical results and analysis

Through the simulation of the lens injection molding process, the volumetric shrinkage and its distributing can be obtained, as shown in Fig.3 and Fig.4.

From the Fig.3 and Fig.4, we can see that, regard-

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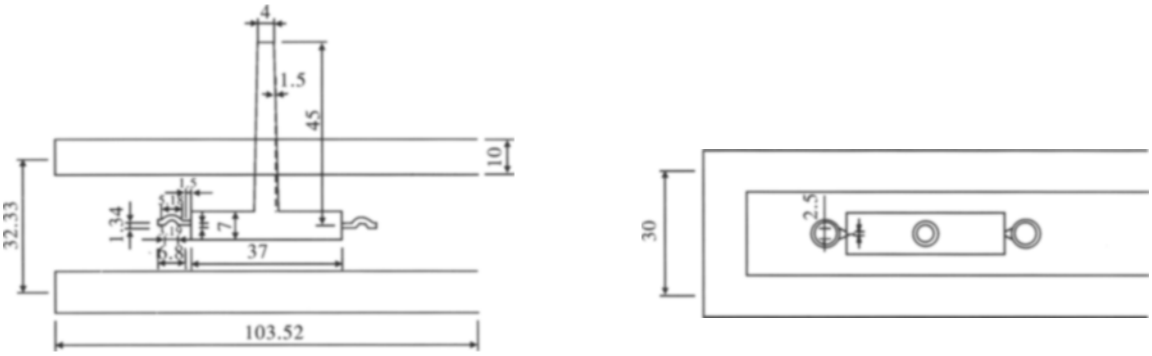
WEN Jialing (温家伶): Assoc. Prof.; E-mail: wjl624365 @ vip.163.com less of convexity or concave, the maximum volumetric shrinkage appears in the centre areas, which is the most significant region for the lens, then decreases gradually and the minimum volumetric shrinkage appears at injection location. In case 1, the maximum volumetric shrinkage is 3.986% and the minimum volumetric shrinkage is -0.163%, the variation is 4.149% and the average volumetric shrinkage is 2.911%. In case 2, the maximum volumetric shrinkage is 4.784% and the minimum volumetric shrinkage is 0.995%, the variation is 3.789% and the average volumetric shrinkage is 3.671%.



(a) Front view of the mold (b) Top view of the mold

Fig.1 The dimensions of mold

(a) The finite model of the mold (b) The finite model of the lens

Fig.2 The models of the numerical experiment

Comparing the results of the two cases, it is easy to find that the process parameters have outstanding influences on the volumetric shrinkage and its distribution.

## 3 The optimization of Process Parameters

The numerical experiment and the orthogonal experimental design were used together to optimize the process conditions.

**Table 2 Optimal parameters and their levels**

| Factors | Level 1 | Level 2 | Level 3 | Level 4 | Level 5 |
|---|---|---|---|---|---|
| Fill time/s | 0.2 | 0/4 | 0.6 | 0.8 | 1 |
| Holding pressure/MPa | 20 | 25 | 30 | 35 | 40 |
| Holding pressure/Times | 3 | 5 | 7 | 9 | 11 |
| Cooling time/s | 6 | 8 | 10 | 12 | 14 |
| Melt temperature/℃ | 230 | 240 | 250 | 260 | 270 |
| Mold temperature/℃ | 50 | 60 | 70 | 80 | 90 |

### 3.1 Orthogonal experimental designs and analysis

The levels of optimal parameters are given in Table 2. Five levels of each parameter were taken into account and orthogonal array table is $L_{25}(5^6)$.

Intuitional analysis is used to evaluate the effect or the importance of a given factor according to the results of orthogonal experimental design. Two steps must be done in direct observation of analysis. First step is to compute the mean $\bar{y}$, the sum $K_{ij}$, the effect of $W_{ij}$ and the different $R_j$ according to equation (1).

$$\bar{y}=\frac{\sum_{i=1}^{n}x_i}{n}, K_{ij}=\sum x_{ij}, W_{ij}=\frac{K_{ij}}{p}-\bar{y}$$

$$R_j=(W_{ij})_{\max}-(W_{ij})_{\min} \qquad (1)$$

where, $\bar{y}$ denotes the average of results, $x_i$ the result of the *i th* experiment, $n$ the times of experiments, $K_{ij}$ the sum of results of a certain level of a factor, $p$ the numbers of level of the factor appears, $W_{ij}$ the effect of the certain level of a factor, $R_j$ the difference of the $(W_{ij})_{\max}$ and the $(W_{ij})_{\min}$ and means influence of factor on index. Second step of intuitional analysis is to draw the trend lines of each factor, then to judge the primary and secondary of factors, finally, to select preferable process conditions.

### 3.2 The optimization process and the results

In order to make volumetric shrinkage less obvious and its distributing more uniform, the following work is done by using an orthogonal experimental design.

**Table 3 Optimum parameters' levels (Average volumetric shrinkage as optimal object)**

| Factor | Level | Factor | Level |
|---|---|---|---|
| Fill time/s | 0.4 | Cooling time/s | 12 |
| Holding pressure/MPa | 40 | Melt temperature/℃ | 270 |
| Holding pressure time/s | 9 | Mold temperature/℃ | 60 |

#### 3.2.1 Average volumetric shrinkage as optimal object (A)

Firstly, the average volumetric shrinkage was looked as an optimizing object, we can obtain the influence degree of process parameters on volumetric shrinkage, whose order is holding pressure > melt temperature > mold temperature > fill time > holding pressure time > cooling time, additionally, the optimum parameters, shown in Table 3, are gained. Through a simulation that uses the data shown in Table 3, we can gain that the average volumetric shrinkage is 2.1582%, which is much less than the results of case 1 and case 2.

### 3.2.2 Volumetric shrinkage variation as optimal object (B)

Secondly, the volumetric shrinkage variation was looked as the optimizing object. Based on the method of orthogonal experimental design, we can draw a conclusion that the influence degree of process parameters on volumetric shrinkage variation are: holding pressure time > holding pressure > melt temperature > fill time > mold temperature > cooling time. In addition, the optimum parameters are obtained, which is shown in Table 4.

Through a simulation that uses the data shown in Table 4, we can gain that the volumetric shrinkage variation is 2.644%, which is much less than the results of case 1 and case 2.

### 3.2.3 Volumetric shrinkage and volumetric shrinkage variation as optimal object together (C)

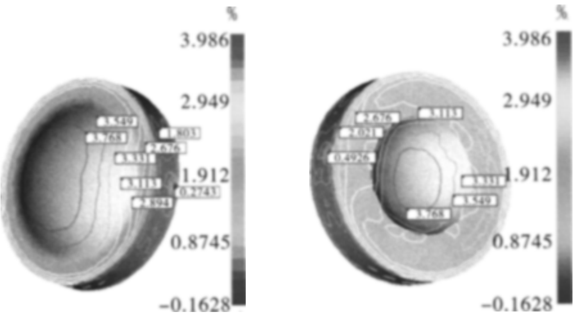
In case A and case B, we gained different optimum parameter levels considering different goals. At last, average volumetric shrinkage and volumetric shrinkage variation were looked as the optimal object, in other words, the influence of process parameters both on average volumetric shrinkage and volumetric shrinkage variation were taken into account together.

**Table 4 Optimum parameters' levels**

| Factor | Level | Factor | Level |
|---|---|---|---|
| Fill time /s | 0.8 | Cooling time /s | 14 |
| Holding pressure /MPa | 40 | Melt temperature /℃ | 270 |
| Holding pressure time /s | 3 | Mold temperature /℃ | 60 |

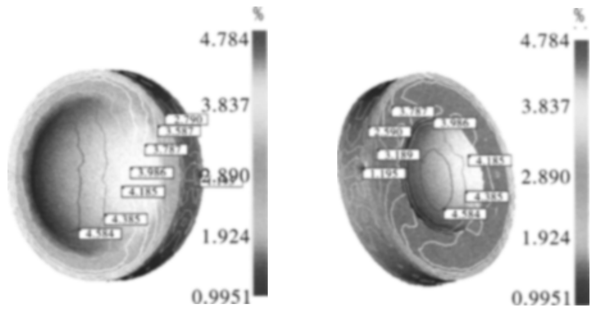
**Table 5 Parameter level considering volumetric shrinkage and volumetric shrinkage variation together**

| Factor | Level | Factor | Level |
|---|---|---|---|
| Fill time /s | 0.4 | Cooling time/s | 12 |
| Holding pressure/MPa | 40 | Melt temperature/℃ | 270 |
| Holding pressure time/s | 3 | Mold temperature/℃ | 60 |



(a) (b)

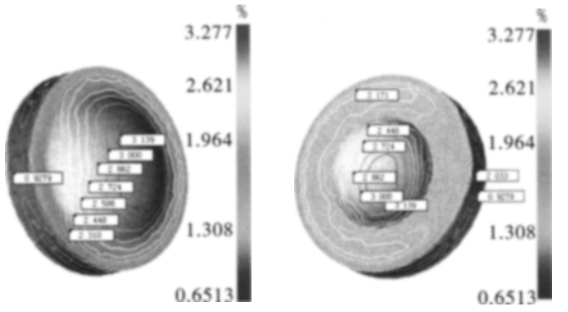
Fig.3 The distribution of volumetric shrinkage for case 1
(a) convexity and (b) on concave



(a) (b)

Fig.4 The distribution of volumetric shrinkage for case 2
(a) convexity and (b) on concave

According to the effect and the significance of each factor in case A and case B, the optimal level of the factor can be obtained, for example, fill time is 0.4 s in case A and 0.8 s in case B, its order of significant is both 4 th in case A and case B. However, the effects of 0.4 s in case A is as much as 0.8 s's in case B, so 0.4 s is selected as fill time. With the same method, we can gain the optimal level of other parameters shown in Table 5.



(a) (b)

Fig.5 The optimized distribution of volumetric shrinkage
(a) convexity and (b) concave

Though a simulation that uses the data shown in Table 5, the volumetric shrinkage and its distributing can be obtained, which is shown in Fig.5. From the Fig.5, we can gain that the maximum volumetric shrinkage is 3.277%, which is 17.8% less than the result of case 1, and that the minimum volumetric shrinkage is 0.651%. The variation is 2.626%, which is 31% less than the result of case 2, and the average volumetric shrinkage is 2.167%, which is 26% less than the result of the case 1.

## 4 Conclusions

a) The process parameters have outstanding influences on the volumetric shrinkage and its distribution of the lens injection molding. As to average volumetric shrinkage, the influence degree of process parameters is: holding pressure > melt temperature > mold temperature > fill time > holding pressure time > cooling time. As to volumetric shrinkage variation, the process parameters' orders are: holding pressure time > holding pressure > melt temperature > fill time > mold temperature > cooling time.

b) Using the numerical experiments and orthogonal experimental design together, the average volumetric shrinkage and volumetric shrinkage variation become less, maximum volumetric shrinkage is 17.8% less than the result of case 1, the volumetric shrinkage variation is 31%

less than the result of case 2, and the average volumetric shrinkage is 26% less than the result of the case 1.

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