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Error Analysis and Compensation Simulation of Aspherical Lens Molding

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Abstract: Aspherical lens molding error is closely related to molding process parameters such as molding temperature, molding speed, annealing rate and annealing holding force. Yet controlling the forming error to improve molding accuracy by optimizing molding process parameters means not only enormous workload, but also more difficulties in reconciling with each other among the various process parameters. In this paper, the methods of mould compensation and joint geometry modification are adopted to pre-correct the surface shape of the mold cavity with the aid of MSC.Marc simulation software. The results of full value error compensation simulation indicate that mould compensation is effective in reducing the compression molding error of aspherical lens, and thereby high-quality non-spherical lens can be moulded.

1. Introduction
Aspherical glass lenses are widely used in the field of optics nowadays. Traditional processing techniques which involve grinding and polishing cannot satisfy the requirements of high-precision volume manufacturing. The glass molding technology puts the softened glass blank into a high-precision mold and molds the aspherical lens under the conditions of heating, pressing and oxygen-free directly. With the high production efficiency, the glass molding technology has become the most advanced optical element preparation technique.

The precision of aspheric lens molding directly determines the quality of the lens. Therefore, controlling the molding error of aspheric lens and improving the molding precision of the lens has become the research hotspots of optical glass lens molding.

2. Error Analysis of Aspherical Lens Molding
The aspherical lens molding process is a relatively complicated process in order to explore the effects of molding process parameters such as molding temperature, molding speed, annealing rate, and annealing retention on molding molding accuracy and molding shape error. The influence of various process parameters on the molding error of aspherical lens was simulated and analyzed with MSC.Marc software.

2.1. Establishment of finite element simulation model
Aspheric lens molding error analysis and compensation simulation are conducted with software MSC.
Marc. The geometric model of the molded aspheric lens is shown in Figure 1. The glass compression molding preform is made of an L-BAL42 glass ball blank. Assuming that the volume of the lens is equal to the volume of the glass sphere, the diameter of the glass sphere blank can be calculated under this assumption. Firstly, use Solid Works design software to establish a three-dimensional solid model of the blank glass beads, and a three-dimensional solid model with aspherical surface upper and lower mold and then preassemble the upper and lower mold as well as the glass balls. Lastly, import assembly file to the finite element software Marc and divide the finite element mesh by the Automesh function to generate the finite element model. The finite element model of the assembly is a tetrahedral element[1].

2.2. Analysis of simulation results

2.2.1. Effect of molding temperature on molding error. Under the conditions of the molding speed $V_m=0.1\text{mm/s}$, the molding pressure $P=500\text{N}$, and the friction coefficient $\mu=0.5$, using different temperatures $570^\circ\text{C}$ and $580^\circ\text{C}$ respectively to conduct glass lens molding simulation. The upper aspheric shape deviation curve is obtained as shown in Figure 2.

When the lens is pressed molding, the molding temperature of the glass blank flows and cures has a decisive influence on the process. From Figure 2, the aspherical surface of the lens curve deviations is reduced with the increasing molding temperature, and the lens curved to the edge deviations increases in shapes at the same time[2]. The reason for this phenomenon is related to the mold temperature effect on the rate of relaxation of residual stress and structural glass. The higher the molding temperature is, and the faster the glass viscoelastic stress relaxation is, the faster the structural relaxation is[3][4]. Therefore the forming error is reduced.

2.2.2. Effect of molding speed on molding error. Under the conditions of molding temperature $T=580^\circ\text{C}$, molding pressure $P=500\text{N}$, the friction coefficient $\mu=0.5$, take different speeds $V_m=0.05\text{mm/s}$ and $V_m=0.1\text{mm/s}$ respectively and the aspheric shape lens curve deviation is as shown in Figure 3.

It can be seen from Figure 3, the faster the molding speed is, the greater the molded lens deviation is[5]. The reasons for this phenomenon, the faster the speed molding, structural relaxation, and stress relaxation time of viscoelastic glass obtained on the shorter, resulting in large residual stress, caused by large residual stress greater deviations in shapes.

2.2.3. Effect of annealing molded error rate. Under the conditions of molding temperature $T=580^\circ\text{C}$, molding pressure $P=500\text{N}$, the friction coefficient $\mu=0.5$, use different annealing rate $U_a=1^\circ\text{C/s}$, $U_a=2^\circ\text{C/s}$ respectively for lens molding simulation. The result of the aspherical shape deviation is shown in Figure 4.
From Figure 4, compared with the molding temperature and the molding speed, the effect of the annealing rate on the shape deviation of the mold forming is less. The reason for the less effect on the molded shape deviations is that the annealing rate has little influence on the residual stress after annealing lens.

2.2.4. Effect of annealing the molded retention errors. Set different annealing holding forces $F_a=500\text{N}$ and $F_a=1000\text{N}$, under the conditions of the molding temperature $T=570{\circ}\text{C}$, press speed $V_m=0.1\text{mm/s}$, the friction coefficient $\mu=0.5$. Apply boundary conditions to the lens molding simulation, the aspherical lens shape variation curve is shown in Figure 5.

Simulation results reveal that in the process of the lens molding annealing, the greater the holding force is, the smaller the shape deviation of the lens is. After the lens is annealed at 1000 N holding force, the shape deviation is only about 5$\mu$m. When the holding force is 500N annealing, the aspherical shape deviation on the lens is increased to about 10.15$\mu$m. Thus it can be seen that with annealing holding force decreasing, the deviation of lens molding increases gradually, and the reason is that a large holding force can copy the shape of the mold better to the lens. The greater the holding force of the annealing is, the better the shape replication effect will be.

From the analysis above, the molding factors such as molding temperature, speed and annealing...
maintaining force have a great influence on the precision of the aspherical lens molding, and the annealing rate can also have an impact on the molding precision of the aspheric lens. The final result of the molding error of the aspherical glass lens is from the cumulative effect of the error caused by all forming factors. Coordinating various molding process parameters reasonably to reduce the error of aspheric lens molding[6]. Therefore, the method of mold compensation by pre-modifying the mold surface, is adopted in engineering field to bring the molding error of aspheric glass lens under control.

3. Aspherical lens molding die compensation simulation

3.1. Lens compression molding die compensation method

Firstly, the finite element software is used to simulate lens molding process and the lens shape deviations can be figured out. And then the molding dies get corrected and compensation by node geometric correction method to control precision of molding of glass lenses.

The principle of the node geometry correction method is to subtract the contraction amount of the corresponding node calculated in the simulation by the node displacement of the target mold profile, thereby obtaining the compensated mold profile.

The specific process is to use MSC. Marc simulation software to simulate the initial mold shape and conduct error analysis to obtain the contracted part shape. In the initial molding simulation, the initial mold shape is the ideal design shape and compare the shape after shrinking the part with the ideal shape. If the deviation of the two parts exceeds the allowable range value, the shape deviation amount is subtracted from the initial mold shape to obtain the first shape. Then, the preform simulation and error analysis are performed again using the first compensated mold. If the deviation between the shape of the part and the ideal target shape still exceeds the error tolerance value, the shape deviation is subtracted from the mold profile again. The shape of the mold that is compensated for the second time is obtained, and the cycle is continued until the deviation of the actual part shape and the target shape reaches the error requirement[7].

In the mold surface compensation, the data analysis and compensation are based on the numerical simulation results in the finite element software, and a new mold curve is generated by combining the reverse modeling function of the Solid Works software.

3.2. Simulation results and analysis of aspheric lens error compensation

3.2.1. Full value error compensation and half value error compensation. The aspheric lens error compensation simulation can adopt a full value error compensation method and a half value error compensation method. The full-value error compensation is to add the difference between the actual value and the target value to the experimental mold, and the half-value error compensation is to add the difference between the actual value and the target value by half to the experimental mold and then use this mold to machine the glass preform to form the lens.

On the basis of the initial mold forming simulation, the error data is inversely added to the initial mold by the full value error compensation method and the half value error compensation method, respectively. After the simulation of the molding, the corresponding shape data is extracted, and the full-value compensation error and the half-value compensation error of the aspheric lens lower surface are obtained, as shown in Figure 6.

It can be seen from Figure 6 that no matter what kind of compensation method, the molding precision of the lens is greatly improved. After the initial error of the lower surface of the lens is compensated by the full value error, the forming precision is obviously improved, and it approaches the ideal value with a maximum error of 1.2μm. After the initial error of the lower surface is compensated by the half-value error, the half-value compensation error curve is improved between the initial error curve and the full-value compensation error curve. Although the forming accuracy is improved, the full-error error compensation is not effective. The maximum error is 3.3μm.

From the values and trends, the error curve of the full-value error compensation is simple and more
controllable. Therefore, if full-value error compensation is adopted in the mold of the aspherical glass lens, the molding precision of the lens will be better, and the error trend will also be easy to control.

3.2.2. Single compensation and multiple compensation simulation. On the basis of the initial simulation results, using the full-value error compensation method, the mold is subjected to three error compensation simulations. The molding error corresponding to each error compensation of the aspherical lens lower surface is shown in Figure 7.

From Figure 7, it can observe that from the beginning of initial simulation, the molding accuracy of the lens surface will be improved compared with the previous one after each compensation of the mold. Maximum error value at the surface of the lens is reduced from 3.6 μm to 0.7 μm, and then to 0.7 μm, and finally to 0.3 μm. The absolute value of error being smaller and smaller indicates that the molding accuracy is increasingly more and more higher[8]. Therefore, it is not easy to obtain the ideal molding results with a single mold compensation. As the number of times of mold compensation increases, the precision of lens molding is getting more higher, but the improvement range of molding error is getting smaller and smaller.

4. Lens profile offset measurement and verification
After the aspheric lens molding experiment is completed, a qualified forming lens is selected and fixed on the measuring platform. The measuring device is started to measure the surface contour. The measurement results of the molded lens and the mold are respectively read, and the lowest point of the mold and the apex of the lens are overlapped, and 5 points are taken at a pitch of 1 mm to obtain a comparison chart of the contour of the molded lens and the mold. The result is shown in Figure 8. As can be seen from Figure 8, the contour curve of the molded lens is substantially identical to the contour curve of the molded mold.
5. Conclusion
One of the commonly used methods for controlling aspherical lens compression moulding error is process control, i.e., to reduce the error by adjusting such molding process parameters such as molding rate, mold temperature, cooling rate, etc. The process control method requires many optimized process parameters and is difficult to implement. Compensation method is to know the mold surface repair quantity in advance, and can form the high-precision lens by pre-correcting the mold surface. MSC. Marc simulation software can be used for several times of correction compensation simulation on the molding process and molding surface, and thus the ideal curve of the mold surface can be optimized in advance. According to the optimized curve of the mold surface, high-quality molding die can be designed and processed, and the molding forming error will be controlled from the origin. Aspherical lens molding experiments indicate that high-precision aspherical glass lens can be molded after many error compensations being conducted by full value error compensation method, and provide a reference for reducing the molding forming error from the angle of mould compensation method.

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References
[1] Zhang Xiaobing, 2015. “Simulation of 3D molding of aspheric optical glass lens based on viscous-rigid model,” Ordnance Material Science and Engineering, 38, pp.68–73.
[2] Duan Hongjie, Li Yihao, Bai Daiping, 2017. “3D FEM Simulation on Aspheric Optical Lens Molding Process,” Journal of Qingdao University of Science and Technology (Natural Science Edition) , 38, pp.93–98.
[3] Li Hui, He Peng, Yu Jianfeng, L. James Lee, Allen Y. Yi, 2015. “Localized rapid heating process for precision chalcogenide glass molding,” Optics & Lasers in Engineering, 73, pp.62–68.
[4] Zhang Xiaobing, Yin Shaohui, Zhu Kejun, et al, 2013. “Simulation technology of compression molding spherical glass lens,”. Optical Technique. 39, pp.204–211.
[5] Zhou Tianfeng, Yan Jiawang, Masuda Jun,et al, 2011. “Investigation on shape transferability in ultraprecision glass molding press for microgrooves,” Precision Engineering, 35, pp.214–220.
[6] Ni Jiajia, Fan Yufeng & Chen Wenhua, 2013. “Simulation Study of Molding of Spherical Optical Glass Lens,”. Laser & Optoelectronics Progress. 50, 032201.
[7] Guo Wange, Wang Huan, Zhang Tao, et al, 2018. “Analysis of structure error for cable net antenna based on the finite element,” Journal of Light Industry, 33(4), pp.66–72.
[8] Chen Fengjun, Yin Shaohui, Huang He et al, 2010. “Profile Error Compensation in Ultra-precision Grinding of Aspheric Surfaces with On-machine Measurement,” International Journal of Machine Tools & Manufacture, 50, pp.480–486.