Intelligent Process-Design-Software-Tool for Precision Glass Molding

F. Klocke[1], G. Liu[1], F. Wang[1], D. Hollstegge[1], D. Wächter[1], O. Dambon[1], A. Y. Yi[2]
[1]*Fraunhofer Institute for Production Technology, Aachen, Germany*
[2]*The Ohio State University, Columbus, USA*

gang.liu@ipt.fraunhofer.de

Abstract

High precision glass molding is becoming a very important manufacturing technology for the production of high quality and complex functionality glass optics. Due to the complexity of production process and high nonlinearity of glass material, effective production process and appropriate mould design can only be fulfilled with try-and-error approaches, which are very time-consuming and strongly experience dependent. In this study, an innovative design concept and an intelligent software tool consists of FEM simulation, based on commercial FEM software ABAQUS, and process optimization, based on MATLAB, has been developed by Fraunhofer IPT, in order to standardize and accelerate the design of precision glass molding process.

1 Intelligent Molding Process Chain

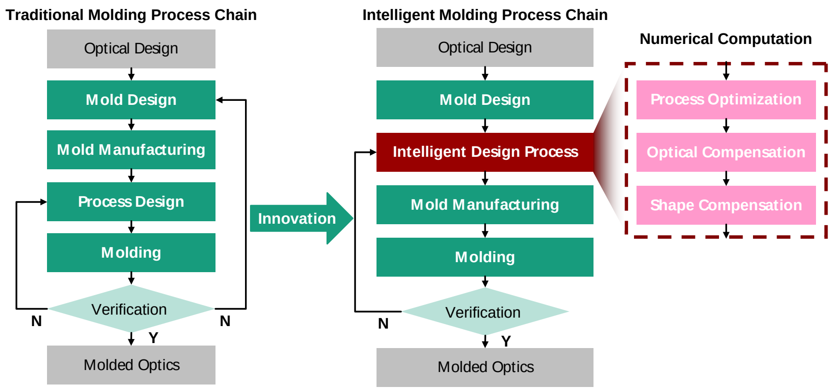

Figure1: Innovative molding process chain

Although this technology has been already applied in industry for many years in an industrial environment, there are still many shortcomings inside process chain: the design and fabrication of proper moulds is very time-consuming and expensive, and the approach for the determination of optimal process parameters is still high labor cost or even impossible. Introducing the intelligent design process, which was developed by Fraunhofer IPT, the high intensive labor activities are replaced by numerical computation, and the efficiency of the entire process chain for non-isothermal glass molding will be significantly increased (Fig. 1).

1.1 Process Optimization

In the precision glass molding process, raw glass material is firstly heated to a temperature above its transition temperature (T_g) and subsequently pressed into a lens shape.

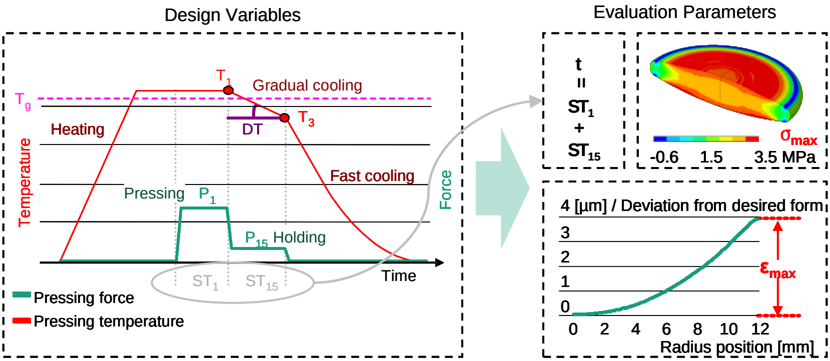

Figure 2: Design variables and evaluation parameters in process optimization

Mathematically, the optimization of precision glass molding process is a multi parameter optimization for complex system. Key parameters of molding process are considered as design variables (Fig. 2), including pressing temperature T_1, stop temperature of gradual cooling T_3, the rate of gradual cooling DT, pressing force P_1 and holding force P_{15}. The upper and lower variation limit of process parameters are determined by experience. FEM process simulation was employed to offer an numerical description of the complex molding process. The outputs of FEM simulation, maximum principal stress (σ_{max}) ,maximum form error (ε_{max}), and molding time (t = pressing time ST_1 + gradual cooling time ST_{15}) are used to evaluate the quality of molded glass optics and efficiency of molding process (Fig. 3), as well as to construct the objective function:

$$\begin{cases} f_{obj} = \delta_1 \sigma^* + \delta_2 \varepsilon^* + \delta_3 t^* \\ \delta_1 + \delta_2 + \delta_3 = 1 \\ \sigma^* = \sigma_{\max} / \sigma_{ov}, \varepsilon^* = \varepsilon_{\max} / \varepsilon_{tol}, t^* = t / t_{emp} \end{cases} \quad 3.1$$

where δ_1, δ_2 and δ_3 are weighting factors, σ^* is non-dimensional maximum principal stress (σ_{ov} is critical Weibull stress, used for fracture probability calculation), ε^* is non-dimensional form deviation (ε_{tol} is the tolerance of form deviation), and t^* is non-dimensional molding time (t_{emp} is empirical molding time).

Sensitivity analysis of design variables is employed firstly to determine the values of weighting factors[1], then mathematical optimization is carried out by means of optimization toolbox of MATLAB (function "fmincon": find minimum of constrained nonlinear multivariable function) to find out optimum process parameters, which minimize the value of objective function via reduced maximum principal stress, form deviation and molding time.

1.3 Optical Compensation

Refractive index under optimized cooling rate is calculated by FEM simulation with self-developed structural-relaxation subroutine in ABAQUS. The variation of focal length and wave front caused by index drop is compensated by adjusting the shape of optical surface[2].

1.4 Shape Compensation

FEM simulation is carried out under previously defined geometry (chapter 1.3) and boundary conditions (chapter 1.2), to predict the shrinkage error of pressed optics, which will be compensated on the shape of mould.

2 Results and Discussion

Table1: Results of process optimization

	Design Variables					Evaluation Parameters		
	T_1 (°C)	T_3 (°C)	DT (°C/s)	P_1 (kN)	P_{15} (kN)	ε_{max} (µm)	σ_{max} (MPa)	t (s)
Initial	565	493	0.9	2.00	1.60	3.16	8.9	112
Optimum	570	503	0.5	1.76	1.83	3.37	3.2	103

To validate the functionality of this design software tool, a case study on molding of an aspheric lens was conducted (Fig. 3).

The process optimization was checked numerically (Tabel 1). 8% reduction of molding time and 64% reduction of maximum principal stress was achieved, while the form deviation only slightly increased (0.2µm, 7%).

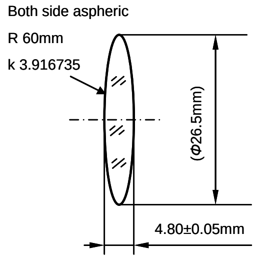

Figure 3: Geometry of the original lens design.

The PV value of the wave-front of the optical-compensated lens, measured on WaveMaster LAB, was about 1.0 wave, compared to the uncompensated lens of 5.4 wave[2].

The shape difference between pressed lens with shape-compensated mould and the original design was confirmed to be less than 0.5µm, which is measured by the Talysurf profiler.

3 Conclusion

An intelligent process design software tool for precision glass molding has been developed by Fraunhofer IPT, based on an innovative design concept. The ability of this design tool was successfully proved by a case study on molding of an aspheric lens.

References:

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[2] F. Klocke, O. Dambon, L. Su, F. Wang, P. He, G. Liu, and A. Y. Yi, "An Integrated Solution for Compensation of Refractive Index Drop and Curve Change in High Precision Glass Molding", Proceedings of Euspen Annual Meeting, Stockholm, Sweden, (2012).