

Table of Contents

Inhaltsverzeichnis

Table of Contents.....	I
Abstract.....	v
Kurzzusammenfassung.....	VI
Symbols and Abbreviations	VII
1 Introduction (Background and Motivation)	1
1.1 Precision glass molding process.....	1
1.2 FEM simulation of precision glass molding process	3
1.3 Fracture in precision glass molding process	6
2 State of the Art	9
2.1 Glass material and properties	9
2.1.1 Composition and atomic structure of optical glasses.....	11
2.1.2 Optical properties.....	12
2.1.3 Density.....	16
2.1.4 Constitutive behaviors	16
2.1.5 Thermal expansion	24
2.1.6 Heat capacity	25
2.1.7 Thermal conductivity	26
2.1.8 Friction coefficient.....	27
2.2 Fracture mechanics	29
2.2.1 Theoretical strength of glass.....	30
2.2.2 Micro defects in optical glasses.....	30
2.2.3 Fracture theory.....	34
2.2.4 Statistical fracture theory.....	42
3 Hypothesis and Research Approach	45
3.1 Current situation and goal of research	45
3.2 Hypothesis.....	45
3.3 Research approach.....	46
4 Observation Systems and Metrology	47
4.1 Machine system	47
4.2 Glass materials.....	49
4.3 Molding tools	50
4.4 Metrology.....	51
4.4.1 Measurement of glass fractural behavior	52

Table of Contents

4.4.2	Comparison between three- and four-point bending tests	56
4.4.3	The four-point bending test.....	58
4.4.4	The three-point bending test	59
5	Modelling Fracture Behavior	61
5.1	Determination of necessary properties of selected glasses	61
5.1.1	Viscosity (VFT equation)	61
5.1.2	Stress-relaxation and thermo-rheological simplicity	62
5.1.3	Temperature dependent elastic moduli	66
5.2	The stress-strain behavior of glass under a constant strain rate	67
5.2.1	Constitutive behavior (single Maxwell element).....	67
5.2.2	Temperature dependence (single Maxwell element).....	70
5.2.3	Measurement of temperature-dependent Young's modulus	71
5.2.4	The stress-strain behavior for generalized Maxwell model	73
5.2.5	Strain energy density under a constant strain rate	74
5.3	Brittle-ductile transition	75
5.3.1	Design of experiments	76
5.3.2	Experimental results and analysis	77
5.3.3	Conclusion of brittle-ductile transition	86
5.4	Statistical fracture analysis.....	87
5.4.1	Experimental results and analysis	87
5.4.2	Conclusion of statistical fracture analysis	95
6	Prediction of Fracture based on FEM Simulation	97
6.1	Fracture of lens in molding experiment.....	97
6.2	FEM simulation of the PGM process	99
6.2.1	Schematic model of the PGM process.....	99
6.2.2	FEM model of the PGM process	101
6.2.3	Simulation results	103
6.3	Calculation of the fracture probability in the PGM process	105
6.3.1	Procedure of statistical fracture analysis for the PGM process.....	106
6.3.2	Results of statistical fracture analysis	107
7	Process Optimization based on Fracture Prediction	111
7.1	Influence of key process parameters on fracture probability.....	111
7.1.1	Design of experiment	111
7.1.2	Investigation results of the influence of key process parameters.....	112
7.2	Optimization of key process parameters	114
7.2.1	Definition of objective function.....	114

7.2.2 Optimization procedure and results	115
7.3 Improved process chain of PGM.....	117
8 Conclusion and Perspective.....	119
Bibliography	121