

Contents

Introduction 1

1	Material Properties of Plastics 3
1.1	Formation and Structure 3
1.2	Types of Plastics 7
1.2.1	Thermoplastic Resins 9
1.2.1.1	Amorphous Thermoplastics 10
1.2.1.2	Semicrystalline Thermoplastics 10
1.2.2	Elastomers 13
1.2.3	Thermosets 13
1.2.4	Polymer Compounds 14
1.2.4.1	Polymer Blends 14
1.2.4.2	Copolymers 15
1.2.4.3	Thermoplastic Elastomers 15
1.2.5	Polymer Composites 18
1.3	Thermal Properties 19
1.3.1	Phase Transitions 20
1.3.1.1	Glass Transition (T_g) 20
1.3.1.2	Flow Temperature (T_f) 20
1.3.1.3	Crystallite Melting Temperature (T_m) 20
1.3.1.4	Thermal Decomposition (T_d) 21
1.3.2	Specific Volume 22
1.3.3	Heat Capacity 24
1.3.4	Heat Conduction 27
1.3.5	Temperature Conduction 30
1.3.5.1	Amorphous Thermoplastics 32
1.3.5.2	Semicrystalline Thermoplastics 33
1.4	Optical Properties 35
1.4.1	Optical Constants 36
1.4.2	Reflection, Transmission and Absorption Behavior 42
1.4.3	Scattering of NIR- and IR-Radiation in Plastics 46
1.4.4	Absorption of NIR-Laser Radiation ($\lambda = 800$ nm to 1200 nm) 49

1.4.4.1	Electronic Excitation	50
1.4.4.2	Vibronic Excitation	51
1.4.4.3	Summarizing Comment	52
1.4.5	Absorption of NIR-Laser Radiation ($\lambda = 1200 \text{ nm}$ to 2500 nm)	54
1.4.6	Absorption of MIR-Laser Radiation ($\lambda = 2.5 \mu\text{m}$ to $25 \mu\text{m}$)	55
1.4.7	Adaptation of NIR-Radiation Absorption by Additives	59
1.4.7.1	Carbon Black	59
1.4.7.2	Inorganic Pigments	61
1.4.7.3	Organic Dyes	66
1.4.7.4	Summarizing Comment	66
	References	66
2	Laser Sources for Plastic Welding	71
2.1	Properties of Laser Radiation	71
2.1.1	Laser Wavelength	73
2.1.2	Intensity Distribution	74
2.1.3	Beam Propagation	74
2.1.4	Focusing Properties	76
2.2	Types of Lasers	78
2.2.1	Diode Lasers (800 to 2000 nm)	78
2.2.2	Nd:YAG-Lasers (1064 nm)	80
2.2.3	Fiber Lasers	83
2.2.4	CO ₂ -Lasers (10.6 μm)	85
2.2.5	Summary	87
2.3	Beam Guiding and Focusing	88
2.3.1	Beam-Guiding Systems	88
2.3.1.1	Glass-Fiber Systems	88
2.3.1.2	Mirror Systems	93
2.3.2	Focusing Systems	95
2.3.2.1	Static Focusing Systems	95
2.3.2.2	Dynamic Focusing Systems	99
2.3.3	Beam-Shaping Optics	100
2.4	Principle Setup of Laser Welding Systems	101
	References	107
3	Basics of Laser Plastic Welding	109
3.1	Heat Generation and Dissipation	109
3.1.1	Absorption of Laser Radiation	109
3.1.1.1	Direct Absorption	109
3.1.1.2	Indirect Absorption	110
3.1.1.3	Hindered Absorption by Internal Scattering	111
3.1.2	Transfer of Laser Energy into Process Heat	114
3.1.3	Dissipation of Process Heat	118
3.1.4	Process Simulation by Complex Computation	121
3.2	Theory of Fusion Process	126

3.2.1	Interdiffusion Process (Reptation Model)	127
3.2.2	Interchange of Macromolecules by Squeeze Flow Process	132
3.2.3	Mixing of Crystalline Phases	133
3.3	Material Compatibility	135
	References	138
4	Process of Laser Plastic Welding	141
4.1	Basic Process Principles	141
4.1.1	Butt-Joint Welding	141
4.1.2	Through-Transmission Welding	143
4.2	Process Types	145
4.2.1	Contour Welding	145
4.2.2	Quasisimultaneous Welding	148
4.2.3	Simultaneous Welding	150
4.2.4	Special Processes	154
4.2.4.1	Mask Laser Welding	154
4.2.4.2	TWIST Laser Welding	155
4.2.4.3	Globo Laser Welding	156
4.2.4.4	IR-Hybrid Laser Welding	158
4.2.4.5	Ultrasonic Hybrid Laser Welding	159
4.2.4.6	Laser-Assisted Tape Laying and Winding	160
4.3	Adaption of Absorption	163
4.3.1	Use of Surface Coatings	163
4.3.2	Use of Absorbing Additives	172
4.3.3	Use of Special Lasers	178
4.4	Design of Joint Geometry	181
4.4.1	Joint Geometries	182
4.4.2	Tolerances and Clamping	186
4.4.3	Obstacles to Avoid	191
4.4.4	Gap Bridging	193
4.5	Methods of Quality Monitoring and Control	195
4.5.1	Quality Control before Processing	196
4.5.2	Quality Control During Processing	199
4.5.2.1	Pyrometric Monitoring	199
4.5.2.2	Thermography Monitoring	203
4.5.2.3	Digital Imaging Monitoring	205
4.5.2.4	Optical Reflection Monitoring	207
4.5.2.5	Mechanical Set-Path Monitoring	208
4.5.2.6	Summary of Monitoring Techniques	209
	References	212
5	Case Studies	217
5.1	Automotive Components	218
5.2	Consumer Goods	223

5.3	Electronic Devices	227
5.4	Medical Devices	232
5.5	Others	238

Index 243