

# Contents

Preface.....	xi
<b>1 Introduction to Fatigue and Tribology of Plastics and Elastomers .....</b>	<b>1</b>
1.1 Introduction to Fatigue.....	1
1.2 Types of Stress .....	1
1.2.1 Tensile and Compressive Stress.....	1
1.2.2 Shear Stress .....	1
1.2.3 Torsional Stress .....	2
1.2.4 Flexural or Bending Stress.....	2
1.2.5 Hoop Stress .....	3
1.3 Fatigue Testing .....	4
1.3.1 Tensile Eccentric Fatigue Machine .....	4
1.3.2 Flexural Eccentric Fatigue Machine .....	8
1.3.3 Cantilevered Beam Eccentric Flexural Fatigue Machine.....	8
1.3.4 Servohydraulic, Electrohydraulic, or Pulsator Fatigue Testing Machines.....	9
1.3.5 MIT Flex Life Machine .....	9
1.3.6 Fatigue and Fracture Standards .....	11
1.4 Understanding Fatigue Testing Data .....	11
1.4.1 Monotonic Stress–Strain Behavior .....	15
1.4.2 Cyclic Stress–Strain Behavior .....	16
1.4.3 Strain-Life Behavior .....	17
1.4.4 Stress-Life Behavior .....	19
1.5 The Fatigue Process .....	20
1.5.1 Crack Initiation .....	20
1.5.2 Crack Growth or Propagation .....	20
1.5.3 Failure .....	21
1.6 Factors That Affect Fatigue Life .....	22
1.7 Design Against Fatigue .....	22
1.8 Summary .....	23
<b>2 Introduction to the Tribology of Plastics and Elastomers.....</b>	<b>25</b>
2.1 Friction.....	25
2.2 Lubrication.....	26
2.3 Wear and Erosion .....	27
2.3.1 Classification of Wear .....	27
2.3.2 Characterizing Wear.....	29
2.4 Tribology Testing .....	31
2.4.1 Testing for Friction.....	31
2.4.2 Wear and Abrasion Tests .....	32
2.4.3 Erosion Tests .....	35
2.4.4 Standard Tests .....	36
2.5 Wear-Resistant Additives .....	36
2.6 Summary .....	38

<b>3</b>	<b>Introduction to Plastics and Polymers</b> .....	<b>39</b>
3.1	Polymerization .....	39
3.2	Copolymers .....	40
3.3	Linear, Branched and Cross-linked Polymers .....	40
3.4	Molecular Weight .....	41
3.5	Thermosets versus Thermoplastics .....	42
3.6	Crystalline versus Amorphous .....	43
3.7	Blends .....	43
3.8	Elastomers .....	45
3.9	Additives .....	45
3.9.1	Fillers, Reinforcement, Composites .....	45
3.9.2	Combustion Modifiers, Fire, Flame Retardants and Smoke Suppressants .....	46
3.9.3	Release Agents and Antiblocking Agents .....	47
3.9.4	Lubricants and Slip Agents, Tribology Additives .....	47
3.9.5	Catalysts .....	47
3.9.6	Impact Modifiers and Tougheners .....	47
3.9.7	UV Stabilizers .....	48
3.9.8	Antistatic Agents .....	48
3.9.9	Plasticizers .....	48
3.9.10	Pigments, Extenders, Dyes, Mica .....	49
3.9.11	Coupling Agents .....	49
3.9.12	Thermal Stabilizers .....	49
3.10	Summary .....	49
<b>4</b>	<b>Styrenic Plastics</b> .....	<b>51</b>
4.1	Background .....	51
4.1.1	Polystyrene .....	51
4.1.2	Acrylonitrile Styrene Acrylate .....	51
4.1.3	Styrene Acrylonitrile .....	52
4.1.4	Acrylonitrile Butadiene Styrene .....	52
4.1.5	Methyl Methacrylate Acrylonitrile Butadiene Styrene .....	52
4.1.6	Styrene Maleic Anhydride .....	53
4.1.7	Styrenic Block Copolymers .....	53
4.1.8	Styrenic Blends .....	53
4.2	Polystyrene .....	54
4.2.1	Fatigue Data .....	54
4.3	Acrylonitrile Styrene Acrylate .....	56
4.3.1	Fatigue Data .....	56
4.4	Styrene Acrylonitrile .....	58
4.4.1	Fatigue Data .....	58
4.5	Acrylonitrile Butadiene Styrene .....	59
4.5.1	Fatigue Data .....	59
4.6	Styrenic Blends .....	69
4.6.1	Fatigue Data .....	69
4.6.2	Tribology Data .....	71

<b>5 Polyether Plastics</b> .....	<b>73</b>
5.1 Background .....	73
5.1.1 Polyoxymethylene (or Acetal Homopolymer) .....	73
5.1.2 Polyoxymethylene Copolymer (POM-Co or Acetal Copolymer) .....	73
5.1.3 Modified Polyphenylene Ether/Polyphenylene Oxides .....	74
5.2 Acetals–POM Homopolymer .....	75
5.2.1 Fatigue Data .....	75
5.2.2 Tribology Data .....	76
5.3 Acetals–POM-Co .....	79
5.3.1 Fatigue Data .....	79
5.3.2 Tribology Data .....	83
5.4 Modified Polyphenylene Ether/Polyphenylene Oxide .....	88
5.4.1 Fatigue Data .....	88
<b>6 Polyesters</b> .....	<b>99</b>
6.1 Background .....	99
6.1.1 Polycarbonate .....	99
6.1.2 Polybutylene Terephthalate .....	100
6.1.3 Polyethylene Terephthalate .....	100
6.1.4 Liquid Crystalline Polymers .....	100
6.1.5 Polycyclohexylene-dimethylene Terephthalate .....	101
6.1.6 Polyphthalate Carbonate .....	102
6.1.7 Polytrimethylene Terephthalate .....	102
6.1.8 Polyester Blends and Alloys .....	102
6.2 Polycarbonate .....	103
6.2.1 Fatigue Data .....	103
6.2.2 Tribology Data .....	113
6.3 Polybutylene Terephthalate .....	118
6.3.1 Fatigue Data .....	118
6.3.2 Tribology Data .....	126
6.4 Polyethylene Terephthalate .....	128
6.4.1 Fatigue Data .....	128
6.4.2 Tribology Data .....	132
6.5 Liquid Crystal Polymer .....	133
6.5.1 Fatigue Data .....	133
6.5.2 Tribology Data .....	134
6.6 Polyphthalate Carbonate .....	135
6.6.1 Fatigue Data .....	135
6.7 Polycyclohexylene-dimethylene Terephthalate .....	136
6.7.1 Fatigue Data .....	136
6.8 Polyester Blends and Alloys .....	137
6.8.1 Fatigue Data .....	137
<b>7 Polyimides</b> .....	<b>149</b>
7.1 Background .....	149
7.1.1 Polyetherimide .....	149
7.1.2 Polyamide-Imide .....	149

7.1.3	Polyimide	152
7.1.4	Imide Polymer Blends	152
7.2	Polyetherimides	153
7.2.1	Fatigue Data	153
7.2.2	Tribology Data	161
7.3	Polyamide-Imides	164
7.3.1	Fatigue Data	164
7.3.2	Tribology Data	166
7.4	Polyimides	169
7.4.1	Fatigue Data	169
7.4.2	Tribology Data	169
<b>8</b>	<b>Polyamides (Nylons)</b>	<b>175</b>
8.1	Background	175
8.1.1	Nylon 6	175
8.1.2	Nylon 11	177
8.1.3	Nylon 12	177
8.1.4	Nylon 66	177
8.1.5	Nylon 610	178
8.1.6	Nylon 612	178
8.1.7	Nylon 666 or 66/6	178
8.1.8	Amorphous Nylon	178
8.1.9	Nylon 46	179
8.1.10	Polyphthalamide (PPA)/High-Performance Polyamide	179
8.1.11	PAA—Polyarylamide	180
8.1.12	PACM 12—Semicrystalline Polyamide	180
8.2	Polyamide 6 (Nylon 6)	181
8.2.1	Fatigue Data	181
8.2.2	Tribology Data	184
8.3	Polyamide 12 (Nylon 12)	185
8.3.1	Fatigue Data	185
8.3.2	Tribology Data	186
8.4	Polyamide 66 (Nylon 66)	188
8.4.1	Fatigue Data	188
8.4.2	Tribology Data	196
8.5	Polyamide 610 (Nylon 610)	217
8.5.1	Fatigue Data	217
8.5.2	Tribology Data	217
8.6	Polyamide 612 (Nylon 612)	218
8.6.1	Fatigue Data	218
8.6.2	Tribology Data	219
8.7	Polyamide 666 (Nylon 666)	221
8.7.1	Fatigue Data	221
8.8	Amorphous Polyamide	222
8.8.1	Fatigue Data	222
8.9	Polyamide 46 (Nylon 46)	223
8.9.1	Fatigue Data	223

8.10	PPA/High-Performance Polyamide	224
8.10.1	Fatigue Data	224
8.11	Polyarylamide	227
8.11.1	Fatigue Data	227
8.12	Semicrystalline Polyamide (PACM 12)	228
8.12.1	Tribology Data	228
<b>9</b>	<b>Polyolefins and Acrylics</b>	<b>229</b>
9.1	Background	229
9.1.1	Polyethylene	229
9.1.2	Cross-linked PE	230
9.1.3	Polypropylene	230
9.1.4	Polymethyl Pentene	231
9.1.5	Ultrahigh Molecular Weight PE	232
9.1.6	Rigid Polyvinyl Chloride	232
9.1.7	Cyclic Olefin Copolymer	232
9.1.8	Polyacrylics	232
9.1.9	Other Olefin Acrylic Polymers	232
9.2	Polyethylene	233
9.2.1	Fatigue Data	233
9.2.2	Tribology Data	233
9.3	Polypropylene	235
9.3.1	Fatigue Data	235
9.4	Ultrahigh-Molecular-Weight PE	237
9.4.1	Fatigue Data	237
9.4.2	Tribology Data	237
9.5	Polyvinyl Chloride	239
9.5.1	Fatigue Data	239
9.6	Acrylics	241
9.6.1	Fatigue Data	241
<b>10</b>	<b>Thermoplastic Elastomers</b>	<b>245</b>
10.1	Background	245
10.1.1	Thermoplastic Polyurethane Elastomers	245
10.1.2	Thermoplastic Copolyester Elastomers	246
10.1.3	Thermoplastic Polyether Block Amide Elastomers	246
10.1.4	Styrenic Block Copolymer TPES	247
10.1.5	Polyolefin TPE	247
10.1.6	Elastomeric Alloy-Thermoplastic Vulcanizate	247
<b>11</b>	<b>Fluoropolymers</b>	<b>249</b>
11.1	Background	249
11.1.1	Polytetrafluoroethylene	249
11.1.2	Polyethylene Chlorotrifluoroethylene	250
11.1.3	Polyethylene Tetrafluoroethylene	250

11.1.4	Fluorinated Ethylene Propylene . . . . .	250
11.1.5	Perfluoro Alkoxy . . . . .	251
11.1.6	Polychlorotrifluoroethylene . . . . .	251
11.1.7	Polyvinylidene Fluoride . . . . .	251
11.1.8	THV™ . . . . .	252
11.1.9	HTE (Hexafluoropropylene–Tetrafluoroethylene–Ethylene copolymer). . . . .	252
11.1.10	Fluoroplastic Melting Points . . . . .	252
11.2	Polytetrafluoroethylene . . . . .	253
11.2.1	Fatigue Data . . . . .	253
11.2.2	Tribology Data . . . . .	254
11.3	Polyethylene Chlorotrifluoroethylene . . . . .	256
11.3.1	Tribology Data . . . . .	256
11.4	Polyethylene Tetrafluoroethylene . . . . .	257
11.4.1	Fatigue Data . . . . .	257
11.4.2	Tribology Data . . . . .	258
11.5	Fluorinated Ethylene Propylene . . . . .	259
11.5.1	Tribology Data . . . . .	259
11.6	Perfluoro Alkoxy . . . . .	260
11.6.1	Fatigue Data . . . . .	260
11.6.2	Tribology Data . . . . .	260
11.7	Polyvinylidene Fluoride . . . . .	262
11.7.1	Fatigue Data . . . . .	262
11.7.2	Tribology Data . . . . .	263
<b>12</b>	<b>High-Temperature Polymers . . . . .</b>	<b>265</b>
12.1	Background . . . . .	265
12.1.1	Polyetheretherketone . . . . .	265
12.1.2	Polyethersulfone . . . . .	265
12.1.3	Polyphenylene Sulfide . . . . .	266
12.1.4	Polysulfone . . . . .	266
12.1.5	Polyphenylsulfone . . . . .	267
12.1.6	Polybenzimidazole . . . . .	267
12.2	Polyetheretherketone . . . . .	268
12.2.1	Fatigue Data . . . . .	268
12.2.2	Tribology Data . . . . .	269
12.3	Polyethersulfone . . . . .	273
12.3.1	Fatigue Data . . . . .	273
12.3.2	Tribology Data . . . . .	275
12.4	Polyphenylene Sulfide . . . . .	276
12.4.1	Fatigue Data . . . . .	276
12.4.2	Tribology Data . . . . .	282
12.5	Polysulfone . . . . .	283
12.5.1	Fatigue Data . . . . .	283
12.5.2	Tribology Data . . . . .	284
	Index . . . . .	287