

Contents

Polymer Science	1	Physical, Chemical, and Thermal Analysis of Thermoplastic Resins	124
Engineering Plastics—An Introduction	3	<i>Stephen B. Driscoll, University of Massachusetts–Lowell</i>	
<i>Peter Martin, Queen’s University Belfast</i>		Analytical Protocols	124
Polymer Structure	4	Molecular Weight Determination from Viscosity	125
Polymer Names	11	Use of Cone and Plate and Parallel Plate Geometries in Melt Rheology	126
Properties of Polymers	12	Chromatography	130
Engineering Thermoplastics	19	Thermoanalysis	132
Engineering Thermosets	26	Characterization of Thermosetting Resins and Polymers	135
Polymer Processing—An Introduction	31	<i>Jeffrey Gotro, InnoCentrix</i>	
<i>Wei Zheng, Adam Kramschuster, and Alex Jordan, University of Wisconsin–Stout</i>		<i>R. Bruce Prime, IBM (retired)</i>	
Extrusion	31	Thermosets	135
Injection Molding	42	Characterization Techniques	136
Blow Molding	51	Characterization of Uncured Thermosetting Resins	137
Rotational Molding	52	Characterization of the Curing Process	139
Compression Molding	53	Cured Thermosets—Physical Property Characterization	150
Transfer Molding	53	Rheological Testing of Polymers	157
Hand Lay-Up Process	53	<i>Gregory W. Kamykowski, TA Instruments–Waters LLC</i>	
Casting	54	Rheology Fundamentals	157
Additive Manufacturing	55	Molten Plastics	158
Effects of Composition, Processing, and Structure on Properties of Engineering Plastics	61	Solid Materials	169
<i>Jose M. Perez, Jr., Pennsylvania College of Technology</i>		Fundamentals of Polymer Additives	173
<i>Jeffrey Hinkley, NASA Langley Research Center (Retired)</i>		<i>Jigneshkumar P. Patel, University of Massachusetts</i>	
Engineering and Commodity Plastics	61	<i>Yanika Schneider, Eurofins EAG</i>	
Composition	61	<i>Malavarayan Sankarasubramanian, Clarkson University</i>	
Thermal and Mechanical Properties	67	<i>Vidya Jayaram, Georgia Institute of Technology</i>	
Viscoelasticity	69	Types of Additives	173
Electrical Properties	69	Mechanical Property Modifiers	173
Optical Properties	70	Physical Property Modifier	181
Chemical Properties	71	Colorants	184
Processing	71	Biological Activity Inhibitors	187
Chemical, Thermal, and Physical Analysis of Plastics	77	Processing Aids	191
Analysis of Polymer Structure	79	Effect of Environment on the Performance of Plastics	199
<i>Chad Brown and David Hukill, Chevron Phillips Chemical Company LLC</i>		<i>Donald E. Duvall, Engineering Systems Inc. (ESi)</i>	
Problem Solving	79	Plasticization, Solvation, and Swelling	199
Molecular Spectroscopy	79	Environmental Stress Cracking	200
Methods of Thermal Analysis	85	Polymer Degradation by Chemical Reaction	200
X-Ray Diffraction Analysis	91	Surface Embrittlement	201
Scheme for Polymer Analysis	91	Temperature Effects	202
Thermal Analysis and Thermal Properties	95	Weathering Testing of Polymeric Materials	205
<i>Robert Pieper, Element Materials Technology</i>		<i>Florian Feil, Atlas Material Testing Technology, GmbH</i>	
Glass Transition Temperature	95	<i>Matt McGreer, Atlas Material Testing Solutions, LLC</i>	
Thermal Analysis	101	Degradation Factors	205
Thermal Properties	108	Weathering Test Methods	208
Determination of Service Temperature	111	Types of Weathering Instruments	209
Thermal Properties of Thermoplastics	112		
Thermal Properties of Thermosets	118		
High-Temperature Resin Systems	121		

Flammability Testing of Plastics	213	Crazing and Fracture in Polymers	286
<i>Andrew Lock (Deceased), Consumer Product Safety Commission</i>		<i>Sya Ensha, EAG Laboratories/Eurofins</i>	
Fire Resistance of Polymeric Materials	213	Behavior of Polymers under Stress	286
Overview of the Burning Process	213	Ductile and Brittle Behaviors	287
Flammability Test Methods	213	Crazing	290
Electrical Testing and Characterization of Plastics	218	Crazing and Shear Yielding	292
<i>Abdullahi Abubakar Mas'ud, Jubail Industrial College</i>		Craze Initiation	292
Electrical Tests	218	Crack Formation and Fracture by Crazing	293
Electrical Properties of Plastics and Their		Crazing in Scanning Electron Microscope Fractography of	
Characterizations	226	Polymers	293
Terms	227	Fracture Mechanics Testing of Plastics	298
Optical Testing and Characterization	231	<i>David Arencón Osuna, Marcelo de Sousa Pais Antunes, Vera</i>	
Transmission and Haze	231	<i>Cristina de Redondo Realinho, José Ignacio Velasco Technical</i>	
Yellowness	231	<i>University of Catalonia</i>	
Refractive Index	232	Historical Development	298
Birefringence	233	Fracture Test Methods for Polymers	299
Surface Irregularity and Contamination	234	Impact Loading and Testing	306
Surface Gloss and Color	235	<i>Zoltán Major, Philipp S. Stelzer, and Florian Kiehas, Johannes</i>	
Ad Hoc Testing	235	<i>Kepler University Linz</i>	
Service Lifetime Assessment of Polymeric Products	236	Material Considerations in Impact Response	306
<i>Dale B. Edwards, and Anand R. Shah, Engineering Systems</i>		Design and Analysis Techniques for Thin Plastic	
<i>Inc. (ESI)</i>		Components	320
Requirements of Service Lifetime Assessment Models	236	Fatigue and Fracture Mechanisms in Polymers	328
What Constitutes a Product Failure	236	<i>Lisa Pruitt, University of California, Berkeley</i>	
Aging Mechanisms in Polymeric Materials	237	<i>Amy Wat, Lawrence Livermore National Laboratory</i>	
Collecting Short-Term Testing Data for a Lifetime		<i>Louis Malito, Exponent, Inc.</i>	
Assessment	238	Fractography and Crack-Tip Microscopy of Common	
Useful Prediction Models	241	Engineering Polymers	328
Mechanical Behavior and Testing of Plastics	245	Micromechanisms of Toughening	331
Mechanical Testing and Properties of Plastics—An		Fatigue Crack Propagation	331
Introduction	247	Factors Affecting Fatigue Performance of Polymers	335
<i>Kayla Thackeray, Instron</i>		Friction and Wear Testing	341
<i>Jeffrey Hinkley, NASA Langley Research Center (Retired)</i>		<i>Kylie E. Van Meter and Brandon A. Krick, Florida</i>	
Tensile Properties	247	<i>State University</i>	
Other Strength/Modulus and Deflection Tests	251	Friction and Wear of Polymers	341
Creep Data Analysis	253	Tribological Applications of Polymers	344
Dynamic Mechanical Properties	253	Tribometers and Instrumentation	344
Impact Toughness	254	Calculating Wear Rate of Polymers	348
Hardness Tests	256	Characterization of Sliding Interface	350
Fatigue Testing	258	Pressure and Velocity Limit	350
Elastomers and Fibers	258	Polymer Testing Best Practices	350
Tests for Determining the Tensile Strength		Degradation Mechanisms of Plastics	353
of Fibers	260	Thermal Stresses and Physical Aging of Plastics	355
Viscoelasticity of Plastics	262	<i>Revised by Donald E. Duvall, Engineering Systems Inc. (ESI)</i>	
<i>Scott M. Olig, U.S. Naval Research Laboratory</i>		Classification of Internal Stresses	355
Viscoelastic Behavior	262	Thermal Stresses	356
Viscoelastic Response to Stress and		Orientation Effects	358
Strain	263	Physical Aging	359
Experimental Analysis	267	Use of High-Modulus Graphite Fibers in Amorphous	
Material Parameters	269	Polymers	362
Creep, Stress Relaxation, and Yielding Mechanisms	272	Environmental Stress Cracking	366
<i>Imane Belyamani, Zayed University</i>		<i>Javier C. Cruz and Jeffrey A. Jansen, The Madison Group</i>	
<i>Jérémy Grondin, École Nationale Supérieure de Mécanique</i>		What Is Environmental Stress Cracking?	367
<i>et d'Aérotechnique</i>		Plastics Susceptibility to Environmental Stress	
Creep in Polymers	272	Cracking	368
Creep Failure Mechanisms in Polymers	273	Testing for Environmental Stress Cracking	372
Prediction of Long-Term Creep Failure in Polymer		Failure Analysis of Environments Stress-Cracking	
Materials	279	Fractures	375

Moisture-Related Failure of Plastics	381	Process Reinforcement Capabilities and Selected Properties	446
<i>Michelle Brown, EMS-CHEMIE (North America) Inc.</i>			
Moisture Concentration and Diffusion	382		
Mechanisms of Moisture-Induced Damage	383	Designing with Plastics	451
Effect of Moisture on the Mechanical Properties of Thermoset Resins	388	<i>Mark T. MacLean-Blevins, MacLean-Blevins & Associates, Inc.</i>	
Effect of Moisture on the Mechanical Properties of Thermoplastics	389	<i>Eric R. Larson, Art of Mass Production</i>	
Moisture Measurement Methods	390	Conceptual Design	451
Organic Chemical-Related Failure of Plastics	393	Concept Development	451
<i>Donald Duvall, Engineering Systems Inc. (ESi)</i>		Plastic Part Design	454
Chemical Interactions	393	Design Validation	460
Physical Interactions	394	Detailed Design	461
Photochemical Aging and Weathering of Polymers—The Basics	399	Design Review	462
<i>Florian Feil, Atlas Material Testing Technology GmbH</i>		Implementation Considerations	463
<i>Matt McGreer and Oscar Cordo, Atlas Material Testing Solutions LLC</i>		Plastic Product Failure	463
Weathering Degradation Factors	399	Avoiding Plastic Product Failure by Proper Plastic Selection and Design	465
Polymer Photochemistry	401	<i>Michael Paloian, Integrated Design Systems, Inc.</i>	
Ultraviolet Stabilization of Polymeric Materials	406	Brief Historical Overview	465
Microbial Degradation of Plastics	411	Product Specifications	465
<i>Hongli Zhang, Robert Dierkes, and Wolfgang R. Streit, Universität Hamburg</i>		Design Considerations	469
Main Synthetic Polymers Released into Nature and the Microbial Enzymes Involved in Their Breakdown	411	Failure Analysis of Plastics	477
Weathering as an Initial Breakdown Mechanism	411	The Failure Analysis Process—An Overview	479
Definition of Biodegradation	412	<i>Todd J. Menna, Element Materials Technology</i>	
Known Enzymes and Those That Still Are Needed to Break Down Plastics	413	Why Failures Occur	479
Measuring Polymer Degradation	414	Causes of Failure	479
Material Selection and Design with Engineering Plastics	419	Why Perform a Failure Analysis?	481
Plastic Design Methods	421	The Failure Analysis Process	481
<i>Mark T. MacLean-Blevins, MacLean-Blevins & Associates, Inc.</i>		Investigation Planning	483
Designing with Plastics in Practice	421	Recommend Corrective Action	487
Benefits of Selecting Plastics	421	Review Implementation	487
When Not to Choose Plastics	422	Forensic Standards	487
Four Key Considerations of Plastics Part Design	422	Visual Examination and Photography in Failure Analysis	488
Part Development Project Sequence	423	<i>Richard P. Baron, Engineering Systems Inc. (ESi)</i>	
Implementation	426	Visual Examination	488
Navigating the Plastic Material Selection Process	428	Professional Digital Cameras	489
<i>Paul J. Gramann, The Madison Group</i>		Photography Basics	490
Consideration of a Plastic Material	428	Field Photographic Documentation	491
Plastic Materials	429	Laboratory Photographic Documentation	491
Motivation for Material Selection	429	Failure Analysis Photography	498
Goal of the Material Selection Process	430	Characterization of Plastics in Failure Analysis	499
Material Selection Process	431	<i>Jeffrey A. Jansen, The Madison Group</i>	
Use of Material Datasheets for Material Selection	433	Fourier Transform Infrared Spectroscopy	500
Post Material Selection	435	Energy-Dispersive X-Ray Spectroscopy	502
Function and Properties Factors in Plastics Processing Selection	437	Differential Scanning Calorimetry	502
Establishing Functional Requirements	437	Thermogravimetric Analysis	504
Process Effects on Molecular Orientation	440	Thermomechanical Analysis	505
Size, Shape, and Design Detail Factors in Process Selection	445	Dynamic Mechanical Analysis	507
Part Size Factors in Process Selection	446	Methods for Molecular Weight Assessment	508
Shape and Design Detail Factors in Process Selection	446	Mechanical Testing	509
		Considerations in the Selection and Use of Test Methods	510
		Case Studies	510
		Ultrasonic Nondestructive Analysis of Plastics	521
		<i>Revised by Paul Kulowitch, Naval Air Warfare Center Aircraft Division</i>	
		System Description	521
		Digital Scanning Systems	528

Complex Geometry Inspection	528	Wear Failures of Plastics	610
Future Trends	530	<i>Gaurav Nagalia, Engineering Systems Inc.</i>	
Fracture of Plastics	533	Interfacial Wear	610
<i>A.R. Shah and D.B. Edwards, Engineering Systems, Inc.</i>		Bulk/Cohesive Wear	611
Deformation and Fracture	533	Elastomers	612
Crack Propagation	536	Thermosets	613
Fractography	537	Glassy Thermoplastics	613
Field Failure in Various Polymers	543	Semicrystalline Thermoplastics	614
Fracture and Fractography of Elastomeric Materials	546	Environmental and Lubricant Effects on the Wear Failures of Polymers	616
<i>Jason T. Poulton, Akron Rubber Development Laboratory, Inc.</i>		Summary and Case Study	616
Root Failure Categories	546	Failure Examples	617
Surface Examination and Analysis of Plastics	553	Wear Failures of Reinforced Polymers	620
<i>Sya Ensha, EAG Laboratories/Eurofins</i>		<i>Abbas Razavykia, Eugenio Brusa, Cristiana Delprete, and Paolo Baldissera, Politecnico di Torino</i>	
<i>Paul West, AFMWorkshop</i>		Influential Parameters That Affect Tribological Performance of Reinforced Polymers	620
<i>Sachin Attavar, EAG Laboratories/Eurofins</i>		Wear Mechanism of Reinforced Polymers	622
Scanning Electron Microscopy for Imaging Plastics	553	Abrasive Wear of Different Types of Reinforced Polymers	622
Scanning Electron Microscopy	553	Adhesive Wear of Different Types of Reinforced Polymers	626
Atomic Force Microscopy for Imaging Polymers	572	Fatigue Failure	631
Atomic Force Microscopy Background	572	<i>Mohammad Amjadi, Arkansas Tech University</i>	
Atomic Force Microscopy Theory	573	Thermal Fatigue Failure versus Mechanical Fatigue Failure	633
Atomic Force Microscopy Application to Polymers	573	Accelerated Life Testing and Aging	646
Chemical Characterization of Surfaces	576	<i>William R. Broughton and Antony S. Maxwell, National Physical Laboratory</i>	
Surface Analysis Fundamentals	576	Designing and Planning Accelerated Test Program	646
X-Ray Photoelectron Spectroscopy	577	Test Data Analysis	647
Time-of-Flight Secondary Ion Mass Spectrometry	580	Thermal Testing	647
Analysis	583	Moisture Conditioning	650
Analysis and Prevention of Plastic Product Failures	587	Weathering	653
Design Related Failures of Plastic Parts	589	Ionizing Radiation	653
<i>Steven M. Kreuzer and Maureen T.F. Reitman,</i>		Biological Degradation	654
<i>Exponent, Inc.</i>		Aqueous and Chemical Environments	654
Product Design Background	589	Environmental Stress Cracking	655
Design Envelope	589	Reference Information	657
Design Tools	592	Glossary of Terms—Characterization and Failure Analysis of Plastics	659
Causes of Design-Related Failures	595	Abbreviations—Characterization and Failure Analysis of Plastics	701
Manufacturing-Related Failures of Plastic Parts	599	Index	705
<i>Vishu Shah, Consultek Consulting Group</i>			
Six Major Causes of Manufacturing-Related Failures of Plastic Parts	599		
Thermoset and Composite Manufacturing Related Failures	605		