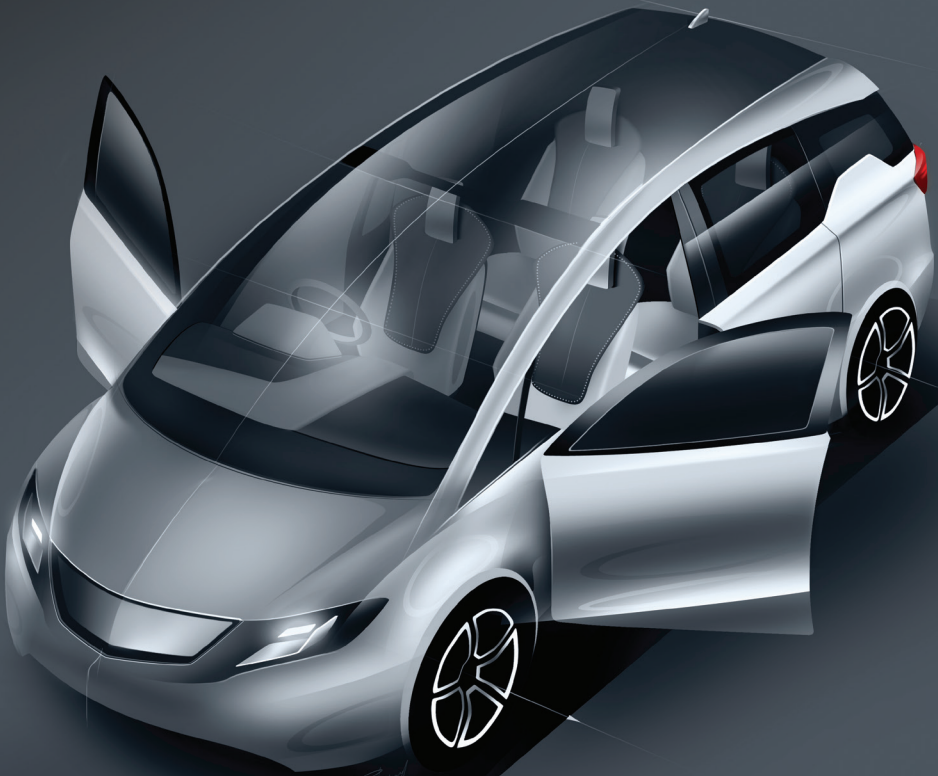


Plastics Application Technology for Safe and Lightweight Automobiles



Sudhakar R. Marur

Table of Contents

Preface	XV
Chapter 1 Introduction to Plastics	
Application Technology	1
1.1 Introduction	1
1.2 Application Development Cycle	2
1.2.1 Voice of the Customer	2
1.2.2 Benchmarking	2
1.2.3 Material Selection	2
1.2.4 Styling and Industrial Design	3
1.2.5 Computer-Aided Design	3
1.2.6 Computer-Aided Engineering	3
1.2.7 Process Modeling	3
1.2.8 Tooling	3
1.2.9 Prototyping	4
1.2.10 Secondary Operations	4
1.2.11 Part Testing	4
1.3 Material Selection Methodology	4
1.3.1 Screening of Material Properties	4
1.3.2 Conversion Processes	5
1.3.3 Structural Requirements	5
1.3.4 Environmental Conditions	5
1.3.5 Assembly and Secondary Operations	5
1.3.6 Cost Factors	5
1.3.7 Regulations and Standards Compliance	5
1.4 Advantages of Plastics	6
1.4.1 Styling Freedom	6
1.4.2 Material Property	6
1.4.3 Performance	6
1.4.4 Part Integration	7
1.4.5 Weight Reduction	7
1.4.6 System-Level Cost Reduction	7
1.5 Key Automotive Plastics Applications	7
1.5.1 Safety and Energy Management	7
1.5.2 Interiors and Occupant Safety	8
1.5.3 Glazing	11

Table of Contents

1.5.4	Plastic-Metal Hybrid Structures	12
1.5.5	Headlamps	13
1.5.6	Body Panels.	14
1.5.7	Under-the-Hood Components.	15
1.6	Summary.	17
1.7	References	17

Chapter 2 Crash and Energy Management Systems23

2.1	Introduction	23
2.2	Safety as an Emerging Global Concern	25
2.3	Regulatory and New Car Assessment Program Crash Test Requirements	25
2.3.1	Pedestrian Impact Tests.	26
2.3.2	Low-Speed Vehicle Damageability or Bumper Structural Tests	27
2.3.3	High-Speed Crashes for Occupant Protection.	28
2.4	Impact and Energy-Absorption Efficiency.	29
2.5	Design of Energy-Absorbing Elements	32
2.6	Pedestrian Protection	33
2.6.1	Vehicle Bumper Stiffness Profile	33
2.6.2	Design of Pedestrian-Safe Bumper Systems	36
2.6.3	Pedestrian Energy Absorbers.	43
2.6.3.1	Pedestrian Energy Absorbers—Middle Load Path	43
2.6.3.2	SUV Energy Absorbers—Upper Load Path	47
2.6.3.3	Undertray—Lower Load Path	49
2.7	Countermeasures for Low-Speed Vehicle Damageability Tests.	51
2.7.1	Bumper Design Challenges	51
2.7.2	Thermoplastic Solitary Beam Solutions	54
2.7.3	Hybrid Plastic-Metal Bumper Beam Solutions	58
2.8	Low-Speed Damageability and Lower-Leg Impact-Compliant Bumper System	61
2.8.1	Conflicting Energy-Absorbing Requirements for Bumpers	61
2.8.2	Dual-Stage Energy-Absorber Approach.	63
2.8.3	Performance Evaluation	65
2.9	Vehicle Structural Integrity for High-Speed Crashes.	66
2.9.1	Hybrid Rail Extensions for Frontal Crashes	67

2.9.2	Plastic Reinforced Body-in-White Structures	72
2.9.3	A Case Study on Roof Crush Countermeasures	74
2.10	Summary	78
2.11	Trends	79
2.12	References	80
Chapter 3 Interiors		87
3.1	Introduction	87
3.2	Instrument Panel	89
3.2.1	Key Drivers in Instrument Panel Design	89
3.2.2	Automotive Instrument Panel Carriers	89
3.2.2.1	Occupant Safety: Head and Knee Impact	89
3.2.2.2	Processing Challenges of Instrument Panel Carriers	91
3.2.2.3	Mold-Filling Simulations of Instrument Panel Carriers	92
3.2.3	Seamless Airbag Design	92
3.2.3.1	Tear Seam Plaque Study	94
3.2.4	Knee Bolster	94
3.2.5	Center Console	95
3.3	Steering Wheel	97
3.3.1	Introduction	97
3.3.2	Metal versus Plastic	98
3.3.3	Design Technology	99
3.3.4	Materials	101
3.3.5	Performance Requirements	101
3.3.5.1	Role of Predictive Engineering	102
3.3.6	Prototyping and Testing	103
3.4	Interior Components	105
3.4.1	Roof Energy Absorber	106
3.4.2	Door Handle and Door Pull Cup	110
3.4.3	Speaker Grille Cover	112
3.5	Summary	113
3.6	Trends	113
3.7	References	114
Chapter 4 Glazing Applications		117
4.1	Automotive Glazing Overview	117
4.2	Automotive Glazing and Global Regulations	118

Table of Contents

- 4.3 Automotive Glazing—Role of Polycarbonate 118
 - 4.3.1 Weight Reduction 119
 - 4.3.2 Styling and Design Freedom 119
- 4.4 Characteristics of a Glazing System 120
- 4.5 Structural Performance 123
 - 4.5.1 Design for Structural Stiffness 123
 - 4.5.2 Role of Restraints 123
 - 4.5.3 Role of Curvature 124
 - 4.5.4 Role of Thickness 125
 - 4.5.5 Importance of Adhesive and Its Characterization 126
 - 4.5.6 Adhesive Testing—Uniaxial Tension 126
 - 4.5.7 Dimensional Stability—Effect of the Coefficient of Thermal Expansion 128
 - 4.5.8 Simulations and Experiments 129
 - 4.5.9 Design of Experiments Approach 130
- 4.6 Acoustic Performance 133
 - 4.6.1 Transmission Loss 133
 - 4.6.2 Transmission Loss Spectrum: Glass versus Polycarbonate 135
 - 4.6.3 Sound Transmission Loss Performance 135
- 4.7 Thermal Management 137
 - 4.7.1 Thermal Modeling of Semitransparent Materials: Spectral Transmission and Absorption 138
 - 4.7.2 HVAC Load—Advantages of Polycarbonate 139
 - 4.7.3 Improved Performance of Electric Vehicles 144
 - 4.7.4 Soak Performance of Polycarbonate Glazing 147
- 4.8 Conversion Process 152
 - 4.8.1 Two-Shot Injection Compression Molding 154
 - 4.8.2 First-Shot Injection Compression Molding 154
 - 4.8.3 Sequential Injection Compression Molding 156
 - 4.8.4 Simultaneous Injection Compression Molding 157
 - 4.8.5 Breathing Injection Compression Molding 157
 - 4.8.6 Second-Shot Injection Overmolding Process 157
 - 4.8.7 Prediction Methodology of Two-Shot Injection Compression Molding Process 158
 - 4.8.8 Part and Tool Development 158
 - 4.8.9 Filling Correlation 160
 - 4.8.10 Warpage Methodology Development 161

4.8.11 Measurement Setup.....	161
4.8.12 Approach.....	163
4.9 Summary.....	165
4.10 Trends.....	166
4.11 References.....	166
Chapter 5 Plastic-Metal Hybrid (PMH) Structures.....	171
5.1 Introduction.....	171
5.2 Why Hybrid Designs?.....	172
5.3 Types of Hybrids.....	173
5.3.1 Overmolding.....	173
5.3.2 Adhesive Bonding.....	174
5.3.3 Collar Joining.....	175
5.3.4 Polymer Injection Forming.....	175
5.3.5 Direct Metal Deposition.....	175
5.3.6 Mechanical Fasteners.....	176
5.3.7 Heat Staking.....	176
5.4 Reinforcing Structure.....	176
5.4.1 Closed-Channel Hybrid Structures.....	176
5.4.2 Open-Channel Hybrid Structures.....	179
5.5 Processing of Hybrids.....	182
5.5.1 Processing of Closed-Channel Hybrid Structures.....	182
5.5.2 Processing of Open-Channel Hybrid Structures.....	184
5.5.3 Mold Design.....	185
5.6 Performance of Hybrid Structures.....	186
5.7 Application of Plastic-Metal Hybrids.....	188
5.7.1 Front-End Module Application Development.....	189
5.7.2 Design Methodology.....	193
5.7.3 Performance Evaluation.....	195
5.8 Summary.....	198
5.9 Trends.....	200
5.10 References.....	200
Chapter 6 Headlamp Applications.....	205
6.1 Automotive Lighting Overview.....	205
6.2 Automotive Lighting Global Regulations.....	207
6.3 Automotive Lighting—Role of Thermoplastics.....	207
6.4 Headlamp Reflectors.....	208
6.4.1 Material Replacement.....	208

Table of Contents

- 6.4.2 Thermal Management 212
- 6.4.3 Structural Performance 219
- 6.4.4 Beam Pattern and Optical Performance 222
- 6.4.5 Stress-Free Reflector through Reflector Bracket 226
- 6.4.6 Tooling and Processing 230
- 6.4.7 Gate Design 230
- 6.4.8 Venting 232
- 6.4.9 Tool Thermal Management 232
- 6.4.10 Tool Surface Treatment 233
- 6.4.11 Processing 234
- 6.5 Headlamp Bezels 234
- 6.6 Headlamp Lenses 235
- 6.7 Headlamp Assembly—Pedestrian Safety 237
- 6.8 Summary 242
- 6.9 Trends 242
- 6.10 References 243

Chapter 7 Body Panels 247

- 7.1 Introduction 247
- 7.2 Functional Requirements for Body Panels 249
 - 7.2.1 Material Selection in Engineering Thermoplastics
Body Panels 251
- 7.3 Fenders 252
 - 7.3.1 Manufacturing Considerations in Fender Design 254
 - 7.3.2 Design for Paintability 258
 - 7.3.3 Material Characterization and Material Model for
Fender Predictive Studies 264
 - 7.3.4 Case Study of Finite Element Analysis to Optimize
Support Configuration 265
 - 7.3.5 Fender Impact Resistance 267
- 7.4 Design and Development of the Thermoplastic Tailgates 268
 - 7.4.1 Functional Requirements of Thermoplastic Tailgates 269
 - 7.4.2 Tailgate Impact Resistance and Structural Rigidity 271
- 7.5 Tank Flap 271
- 7.6 Spoiler 272
- 7.7 Summary 273
- 7.8 Trends 273
- 7.9 References 274

Chapter 8 Under-the-Hood Applications.....277

8.1	Introduction	277
8.2	Material Requirements for Under-the-Hood Applications	278
8.2.1	Heat Aging	278
8.2.2	Chemical Resistance	279
8.2.3	Types of Engineering Plastics in Under-the-Hood Applications.....	280
8.3	Under-the-Hood Application Examples.....	282
8.3.1	Oil Pans.....	283
8.3.2	Wire Coating.....	284
8.3.3	Engine Cover	285
8.3.4	Fuel Lines	287
8.4	Designing of Under-the-Hood Components	287
8.4.1	Turbo Air Duct	288
8.4.1.1	Design Validation	290
8.4.2	Throttle Body	292
8.4.2.1	Types of Throttle Body	292
8.4.2.2	Materials for the Throttle Body.....	293
8.4.2.3	Predictive Tools to Drive Thermoplastics Usage in Electronic Throttle Body	294
8.4.2.4	Processing of Throttle Body.....	297
8.4.2.5	Current Status of Thermoplastics in Electronic Throttle Body.....	299
8.5	Summary.....	300
8.6	Trends	300
8.6.1	Material Advancements	301
8.6.2	Processing Advancements	301
8.6.3	Secondary Process Advancements	302
8.6.4	Design Trends.....	302
8.6.5	Green Trends.....	303
8.7	References	303

Chapter 9 Sustainability in the Automotive Industry 307

9.1	Introduction	307
9.1.1	Sustainability Trends in the Automotive Industry	308
9.2	Lightweighting and Fuel Efficiency	308
9.2.1	Materials for Lightweighting.....	309

Table of Contents

- 9.2.2 Quantifying Environmental Benefits of Lightweighting through Life Cycle Assessment 311
- 9.2.3 Life Cycle Assessment Case Studies for Lightweight Materials 311
- 9.2.4 The Future of Lightweighting with Plastics. 314
- 9.2.5 Design for Sustainability. 314
- 9.3 Renewable-Sourced or Bio-Based Materials for the Automotive Industry 315
 - 9.3.1 Why Renewable Resources?. 315
 - 9.3.2 Carbon Footprint of Bio-Based Raw Materials 316
 - 9.3.3 Bio-Based Materials for Plastics. 317
 - 9.3.3.1 Cellulosic Plant Fibers 317
 - 9.3.3.2 Bio-Based Polymers Made from Monomers or Intermediates from Renewable Resources 319
 - 9.3.3.3 Highly Biodegradable Polymers from Renewable Resources 320
 - 9.3.4 Limitations of Sourcing Raw Materials from Renewable Resources to Make Polymers 322
 - 9.3.5 Emerging Bio-Based Raw Materials 322
 - 9.3.6 Bio-Based Plastics for the Future Automotive Industry 323
- 9.4 End-of-Life Scenarios 324
 - 9.4.1 Recycling in the Automotive Industry 324
 - 9.4.2 End-of-Life Options for Selected Polymer Families 326
 - 9.4.3 Challenges and Limitations to Plastics Recycling. 326
 - 9.4.4 Effect of Recycling on Carbon Footprint Reduction. 330
 - 9.4.5 Reuse 330
 - 9.4.6 End-of-Life Scenario for the Future. 330
- 9.5 Summary 331
- 9.6 Trends 331
- 9.7 References 332

Abbreviations 341

Index 345

About the Editor. 353

- Contributors 353

Plastics Application Technology for Safe and Lightweight Automobiles

Sudhakar R. Marur

This book focuses on using plastics in automobiles for traditional applications such as interiors and body panels, and for more advanced applications such as glazing and under-the-hood components. It provides application technology development for various aspects of automotive design—concept design, CAD modeling, predictive engineering methods through CAE, manufacturing method simulation, and prototype and tool making. It is based on a decade of research and real-world application of the authors.

Described are design and manufacturing aspects of energy absorbers, fenders, front-end modules, instrument panels, steering wheels, headlamp assemblies, throttle bodies, glazing, and tailgates, as well as exterior components such as roof racks, wipers, door handles, and rearview mirror assemblies. Using engineering thermoplastics for such applications will improve safety and reduce the weight of next-generation automobiles.

Readers will gain an understanding of design and manufacturing methodologies of plastics and the means to apply them to a particular vehicle platform. The intent is to help further engineering expertise about using plastics in automobiles so that they can be safer, lighter, and more energy efficient.



About the Editor Sudhakar R. Marur led the plastics application technology laboratory, as its technical director, for SABIC Innovative Plastics in Bangalore, India. Under his leadership, the team

developed plastics application solutions for automotive companies worldwide. He has more than 23 years of experience in industrial R&D. He earned his PhD from the Indian Institute of Technology (IIT), Bombay, specializing in computational nonlinear structural dynamics, and did his postdoctoral research on nonlinear vibrations and elementology at National Aerospace Laboratories.

SAE
INTERNATIONAL™

R-415

ISBN 978-0-7680-7640-0



9 780768 076400