CHAPTER 1

Introduction to Composites and Care of Composite Parts

1.1 Definition of Composites
1.2 History of Composite Materials
1.3 Advantages and Disadvantages of Composites
   1.3.1 Advantages of Composites
   1.3.2 Disadvantages of Thermosetting Resin Composites
   1.3.3 Advantages of Thermosetting Resin Composites
   1.3.4 Advantages of Thermoplastic Resin Composites
   1.3.5 Disadvantages of Thermoplastic Resin Composites
1.4 Applications of Composites to Modern Aircraft, Yachts, Cars, and Trains
   1.4.1 Early Aircraft Structures
   1.4.2 Modern Aircraft Structures and Other Applications
   1.4.3 Projected Use of Composites
1.5 Care of Composite Parts
   1.5.1 Sources of Damage to Composite Parts
      1.5.1.1 Physical or Chemical Damage
      1.5.1.2 Deterioration in Normal Service
   1.5.2 Avoidance of Damage and Reduction of Deterioration in Service

References

CHAPTER 2

Materials

2.1 Fiber Reinforcement
   2.1.1 Comparison of Some High-Performance Fibers and Common Metals
   2.1.2 Glass Fiber
      2.1.2.1 Glass Manufacture
      2.1.2.2 Glass Fiber Manufacture
2.6 Core Materials

2.6.1 Wood

2.6.2 Foam Core Materials

2.6.2.1 Material Types

2.6.2.2 Foam Density

2.6.2.3 Advantages and Disadvantages

2.6.3 Honeycomb Core Materials

2.6.3.1 Honeycomb Material Types

2.6.3.2 Cell Shapes

2.6.3.3 Honeycomb Densities and Cell Sizes

2.6.4 Fluted Core

2.6.5 Syntactic Core

2.7 Syntactic Foams and Potting Compounds

2.7.1 Filler Materials for Potting Compounds, Resin Systems, and Adhesives

2.7.2 Other Fillers

2.8 Protective Coatings

2.8.1 Sealants

2.8.1.1 Old-Generation Thiokol Sealants

2.8.1.2 New-Generation Polythioether Sealants

2.8.1.3 Silicone Sealants

2.8.1.4 Viton Rubber Sealants

2.8.2 Primers

2.8.3 Finishes

2.8.4 Conductive Coatings

2.8.5 Erosion-Resistant Coatings

2.8.6 Other Protective Coatings

References

Bibliography

CHAPTER 3

Handling and Storage

3.1 Shipping and Receiving

3.2 Temperature Requirements

3.3 Storage Practices

3.3.1 Temperature Requirements

3.3.1.1 Dry Fabrics

3.3.1.2 Storage of Pre-preg, Film, and Paste Adhesives, Potting Compounds, and Primers

3.3.1.2.1 Thermoplastic Resins and Their Composites
3.3.1.3 Storage of Sealants for Aircraft Use 95
3.3.1.4 Storage of Consumable Items for Composite and Bonded Metal Repairs 96
3.3.2 Cleanliness and Damage Prevention 96
3.3.3 Moisture Damage Prevention 97
3.3.4 Identification 98
3.3.5 Release Notes and Approved Certificates 99
3.4 Shelf Life/Out-Time 101
3.5 Kitting 102
3.6 Recertification 102
3.7 Care of Materials in the Hangar or Workshop 103

CHAPTER 4
Manufacturing Techniques 105
4.1 Filament Winding 105
4.2 Lay-Up Methods for Fabrics and Tapes 107
  4.2.1 Hand Lay-Up (Wet and Pre-preg Laminating) 107
  4.2.2 Automated Lay-Up 108
4.3 Pultrusion 109
4.4 Resin Transfer Molding 110
4.5 Injection Molding 111
4.6 Tow Placement 113
4.7 Press Molding 114
4.8 Vacuum Bonding 114
4.9 Autoclave Bonding 114
4.10 Oven Curing 118
References 118
Other Useful Reading 118

CHAPTER 5
Original Design Criteria 119
5.1 Principal, Primary, and Secondary Structures 119
  5.1.1 Sources of Damage to Composite Airframe Components 122
  5.1.2 Consequences of Failure 123
5.2 Types of Composite Structures 123
  5.2.1 Monolithic Laminated Structures (Solid Laminates) 123
  5.2.2 Sandwich Structures 125
CHAPTER 5

Ply Orientation 128
  5.3.1 Warp Clock 128
  5.3.2 Balance and Symmetry 130
  5.3.3 Nesting and Stacking 133

Core Orientation and Other Design Characteristics 134

Operational Environment 134
  5.5.1 Temperature 135
  5.5.2 Humidity 135
  5.5.3 Contaminants 135
  5.5.4 Erosion 136
  5.5.5 Thermal Stresses 137
  5.5.6 Hygrothermal Effects 137
  5.5.7 Fire Resistance 137

Electrical Requirements 138
  5.6.1 Galvanic Corrosion 139
  5.6.2 Electromagnetic Interference 141
  5.6.3 Electrostatic Discharge 142
  5.6.4 Lightning Strike Energy Dispersion 143
  5.6.5 Radar Transmissivity 143

Mechanical Requirements 144
  5.7.1 Tensile and Flexural Strength 144
  5.7.2 Stiffness 145
  5.7.3 Fatigue 145
  5.7.4 Impact Resistance 147
  5.7.5 Creep 148

Attachments/Joints 149
  5.8.1 Bonded Joints 149
  5.8.2 Mechanically Fastened/Riveted Joints 153

Other Design Requirements 154
  5.9.1 Aerodynamic Smoothness 154
  5.9.2 Weight and Balance 154

References 154

CHAPTER 6

Safety and Environment 157

6.1 Introduction 157
6.2 Workshop Conditions for Good Bonding 160
6.3 Respirable Fibers and Dust 162
  6.3.1 Fiberglass 162
  6.3.2 Carbon and Graphite Fibers 162
CHAPTER 7

Damage and Repair Assessment

7.1 Visual Inspection
7.2 Tap Test
7.3 Ultrasonic Inspection
7.4 X-Ray Methods
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.5 Eddy Current Inspection</td>
<td>198</td>
</tr>
<tr>
<td>7.6 Thermography</td>
<td>199</td>
</tr>
<tr>
<td>7.7 Bond Testers</td>
<td>200</td>
</tr>
<tr>
<td>7.8 Moisture Meters</td>
<td>200</td>
</tr>
<tr>
<td>7.9 Drying of Composites Prior to Repair</td>
<td>202</td>
</tr>
<tr>
<td>7.10 Interferometry/Shearography</td>
<td>203</td>
</tr>
<tr>
<td>7.11 Damage Types</td>
<td>206</td>
</tr>
<tr>
<td>7.12 Sources of Mechanical Damage</td>
<td>208</td>
</tr>
<tr>
<td>7.13 Damage Mapping</td>
<td>209</td>
</tr>
<tr>
<td>7.13.1 Assessment of Damage Significance</td>
<td>210</td>
</tr>
<tr>
<td>References</td>
<td>215</td>
</tr>
<tr>
<td><strong>CHAPTER 8</strong></td>
<td></td>
</tr>
<tr>
<td>Source Documents</td>
<td>217</td>
</tr>
<tr>
<td>8.1 Revision Systems</td>
<td>218</td>
</tr>
<tr>
<td>8.2 Effectivity</td>
<td>218</td>
</tr>
<tr>
<td>8.3 Drawing Numbering Systems</td>
<td>219</td>
</tr>
<tr>
<td>8.4 Internal Documents</td>
<td>220</td>
</tr>
<tr>
<td>8.5 Material and Process Specifications</td>
<td>221</td>
</tr>
<tr>
<td>8.6 Original Equipment Manufacturer Documents</td>
<td>223</td>
</tr>
<tr>
<td>8.7 Regulatory Documents</td>
<td>224</td>
</tr>
<tr>
<td>8.8 Airlines for America (formerly Air Transport Association of America) ATA 100 System</td>
<td>225</td>
</tr>
<tr>
<td>8.9 Aircraft Maintenance Manual</td>
<td>225</td>
</tr>
<tr>
<td>8.10 Component Maintenance Manual</td>
<td>225</td>
</tr>
<tr>
<td>8.11 Overhaul Manual</td>
<td>226</td>
</tr>
<tr>
<td>8.12 Illustrated Parts Catalog</td>
<td>226</td>
</tr>
<tr>
<td>8.13 Structural Repair Manual</td>
<td>226</td>
</tr>
<tr>
<td>8.14 Engine Manual</td>
<td>227</td>
</tr>
<tr>
<td><strong>CHAPTER 9</strong></td>
<td></td>
</tr>
<tr>
<td>Structural Repair Manual (SRM) Repair</td>
<td>229</td>
</tr>
<tr>
<td>Method Selection</td>
<td>229</td>
</tr>
<tr>
<td>9.1 Component Identification</td>
<td>229</td>
</tr>
<tr>
<td>9.2 Damage Classification</td>
<td>230</td>
</tr>
<tr>
<td>9.2.1 Damage Terminology</td>
<td>230</td>
</tr>
<tr>
<td>9.2.2 Critical Areas</td>
<td>231</td>
</tr>
<tr>
<td>9.2.3 Allowable/Negligible Damage</td>
<td>231</td>
</tr>
<tr>
<td>9.2.4 Repairable Damage</td>
<td>231</td>
</tr>
</tbody>
</table>
CHAPTER 10

Repair Techniques

10.1 Preparation

10.1.1 Paint Removal

10.1.2 Disbonding Methods
   10.1.2.1 Disbonding Adhesively Bonded Metal Parts
   10.1.2.2 Disbonding Composite Parts

10.1.3 Damage Removal
   10.1.3.1 Damage Removal from Metal Parts
   10.1.3.2 Removal of Skin and Doubler Material
   10.1.3.3 Damage Removal from Composite Parts
   10.1.3.4 Removal of Core Material
   10.1.3.5 Removal of Surface Corrosion

10.1.4 Moisture and Contamination Removal

10.1.5 Surface Preparation of Composites: Repair Sanding and Ply Determination
   10.1.5.1 Abrading
   10.1.5.2 Taper Sanding/Scarfing
   10.1.5.3 Step Sanding and Cutting

10.1.6 Water Break Test

10.1.7 Metallic Surface Preparation

10.2 Typical Repairs
   10.2.1 Edge Band Repairs
   10.2.2 Repair of Damage to Core and One Skin
   10.2.3 Repair of Damage to Core and Both Skins
   10.2.4 Hybrid Repairs
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.2.5 Blind Repairs</td>
<td>259</td>
</tr>
<tr>
<td>10.2.6 Injected Repairs</td>
<td>265</td>
</tr>
<tr>
<td>10.2.7 Solid Laminate Repairs</td>
<td>266</td>
</tr>
<tr>
<td>10.2.8 Potted Repairs</td>
<td>266</td>
</tr>
<tr>
<td>10.2.9 Metal-to-Metal Bonding</td>
<td>267</td>
</tr>
<tr>
<td>10.2.10 Plastic Welding (Solvent or Heat)</td>
<td>268</td>
</tr>
<tr>
<td>10.3 Adhesive Usage</td>
<td>268</td>
</tr>
<tr>
<td>10.4 Bagging Materials, Release Films, Release Fabrics, Peel Plies, Breather Cloths, Bleeder Cloths, Bleed-Out Fabrics, and Application Techniques</td>
<td>268</td>
</tr>
<tr>
<td>10.4.1 Terminology</td>
<td>268</td>
</tr>
<tr>
<td>10.4.2 Selection Criteria</td>
<td>271</td>
</tr>
<tr>
<td>10.4.3 Surface Versus Envelope Bagging</td>
<td>272</td>
</tr>
<tr>
<td>10.4.4 Pleating</td>
<td>274</td>
</tr>
<tr>
<td>10.4.5 Bagging Sequence</td>
<td>274</td>
</tr>
<tr>
<td>10.4.6 Vacuum Requirements and Principles</td>
<td>274</td>
</tr>
<tr>
<td>10.4.6.1 Vacuum Bonding</td>
<td>274</td>
</tr>
<tr>
<td>10.4.6.2 Application of Vacuum Pressure to Plates and Assemblies Using Nonperforated Honeycomb</td>
<td>275</td>
</tr>
<tr>
<td>10.4.6.3 Practical Techniques to Ensure Adequate Applied Vacuum Pressure to Parts under Repair</td>
<td>277</td>
</tr>
<tr>
<td>10.4.7 Caul Plate and Dam Usage</td>
<td>281</td>
</tr>
<tr>
<td>10.4.8 Vertical Bleed Method</td>
<td>282</td>
</tr>
<tr>
<td>10.4.9 Squeeze-Out (Edge Bleed-Out) Method</td>
<td>283</td>
</tr>
<tr>
<td>10.4.10 Zero-Bleed Method</td>
<td>284</td>
</tr>
<tr>
<td>10.4.11 Ply Compaction and Debulking</td>
<td>284</td>
</tr>
<tr>
<td>10.4.12 Debagging Precautions and Typical Problems</td>
<td>285</td>
</tr>
<tr>
<td>10.5 Curing Stages and Temperatures—Heating Techniques</td>
<td>285</td>
</tr>
<tr>
<td>10.5.1 Curing Stage Definitions</td>
<td>285</td>
</tr>
<tr>
<td>10.5.2 Low-Temperature Cure</td>
<td>286</td>
</tr>
<tr>
<td>10.5.3 Elevated-Temperature Cure</td>
<td>286</td>
</tr>
<tr>
<td>10.5.4 Direct versus Indirect Heating</td>
<td>286</td>
</tr>
<tr>
<td>10.5.5 Ramp Rates and Soak Cycles</td>
<td>287</td>
</tr>
<tr>
<td>10.5.6 Temperature Control and Monitoring</td>
<td>287</td>
</tr>
<tr>
<td>10.5.7 Thermocouple Placement</td>
<td>287</td>
</tr>
<tr>
<td>10.5.8 Temperature Control Problems</td>
<td>289</td>
</tr>
<tr>
<td>10.5.9 Hot Bonder and Heater Blanket Usage</td>
<td>290</td>
</tr>
<tr>
<td>10.5.10 Heat Sinks</td>
<td>291</td>
</tr>
<tr>
<td>10.5.11 Thermocouples</td>
<td>292</td>
</tr>
<tr>
<td>10.5.12 Distortion of Parts During Heating or Cooling</td>
<td>293</td>
</tr>
<tr>
<td>10.6 Post-Repair Inspection</td>
<td>294</td>
</tr>
<tr>
<td>10.7 Surface Restoration</td>
<td>295</td>
</tr>
<tr>
<td>References</td>
<td>297</td>
</tr>
</tbody>
</table>
## Contents

### 12. Calibration Records
- 12.2 Calibration Records 351
- 12.3 Material Control Records 352
- 12.4 Component Documentation 354
- 12.5 Training Records 354

### 13. Shop Equipment and Hand Tools 357
- 13.1 Hand Tools and Techniques 357
  - 13.1.1 Drills 358
  - 13.1.2 High-Speed Grinders 359
  - 13.1.3 Cutting Utensils 361
  - 13.1.4 Hand Routers 361
  - 13.1.5 Orbital Sanders 362
  - 13.1.6 Cast Cutter (Oscillating Saw) 362
  - 13.1.7 Painting Equipment 363
  - 13.1.8 Resin Applicators 363
- 13.2 Shop Equipment 363
  - 13.2.1 Bandsaws 363
  - 13.2.2 Air Compressors 364
- 13.3 Heating Devices 365
- 13.4 Measuring Devices 367
- 13.5 Health and Safety Equipment 368

### References 369

### Tooling and Mold Making 371
- 14.1 Introduction 371
- 14.2 Caul Plate and Dam Fabrication 372
- 14.3 Splash Mold Making 374
- 14.4 Release Agents/Films 374
- 14.5 Simple Room-Temperature Tooling 375
- 14.6 Room-Temperature Curing Pre-Preg Tooling 376
  - 14.6.1 Lay-Up 377
  - 14.6.2 De-bulk Procedure 378
  - 14.6.3 Final Bagging Procedure 379
  - 14.6.4 Autoclave Cure 379
  - 14.6.5 Time Limits 380
  - 14.6.6 Step Post-Curing Procedure After Room-Temperature or Low-Temperature Initial Cure 380
CHAPTER 15

Metal Bonding

15.1 Introduction
15.1.1 History and Requirements
15.1.2 Principles of Adhesion
15.1.3 Advantages and Disadvantages of Metal Bonding

15.2 Surface Preparation Methods
15.2.1 Abrasive Cleaning
15.2.2 Semco Pasa-Jell Now Owned by PPG Industries
15.2.3 Hydrofluoric Acid Etching
15.2.4 Grit Blast/Silane
15.2.5 Alodine or Alochrom 1200
15.2.6 Sol-Gel Process
15.2.7 FPL Etch
15.2.8 Chromic Acid Anodizing
15.2.9 Phosphoric Acid Anodizing

15.3 Other Surface Preparations

15.4 Primers
15.4.1 Reasons for Using Primers
15.4.2 Primer Types
15.4.3 Application of Primers
15.4.4 Curing/Drying
15.4.5 Thickness Verification

15.5 Handling Primers

References

Bibliography
### CHAPTER 16

**Design Guide for Composite Parts** 411

16.1 Introduction 411
16.2 Analysis of Reports Received 412
16.3 Other Required Design Features Not Mentioned in the Analyzed Reports 430

References 433

### CHAPTER 17

**Repair Design** 435

17.1 General Repair Design 435
17.1.1 Introduction to Repair Design 435
17.1.2 Laminate Loading 436
17.1.2.1 Tension and Compression Loads and Strains 436
17.1.2.2 Shear Stress and Strain 437
17.1.2.3 Poisson's Ratio 437
17.1.3 Repair Philosophy and Design Requirements 439
17.1.3.1 Certification Load Capacity 439
17.1.3.2 Repair Categorization 443

17.2 Laminate Repair Design 444
17.2.1 Introduction to Laminate Repair Design 444
17.2.2 Laminate Repair Design Considerations 445
17.2.2.1 Stiffness 445
17.2.2.2 Strength 447
17.2.2.3 Stability 448
17.2.2.4 Environmental Effects and Protection 448
17.2.2.4.1 Operational and Glass Transition Temperatures (T_g) 448
17.2.2.4.2 Lightning and Electrostatic Protection 448
17.2.2.5 Other Repair Design Considerations 455
17.2.2.6 Laminate Repair Recommendations 456

17.2.3 Laminate Analysis Techniques for Repair Design 457
17.2.3.1 Introduction to Simplified Analysis Techniques 457
17.2.3.2 Elastic Modulus (E) Analysis 460
17.2.3.3 Strength (F) Analysis 463
17.2.3.4 Poisson's Ratio (ν_0) Analysis 463
17.2.3.5 In-Plane Shear Modulus (G) 466

17.2.4 In-Plane Shear Strength (τ) 467

17.3 Core Repair Design 471
17.3.1 Function and Loading of Core in Sandwich Construction 471
17.3.2 Core Material, Density, and Cell Size 472
17.3.3 Core Repair Design Recommendations 473
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>17.4.1</td>
<td>Introduction to Bonded Joints</td>
<td>474</td>
</tr>
<tr>
<td>17.4.2</td>
<td>Types of Bonded Joints</td>
<td>475</td>
</tr>
<tr>
<td>17.4.3</td>
<td>Failure Modes of Bonded Joints</td>
<td>477</td>
</tr>
<tr>
<td>17.4.4</td>
<td>Adhesive Behavior in Bonded Joints</td>
<td>478</td>
</tr>
<tr>
<td>17.4.4.1</td>
<td>Adhesive Shear Stress and Strain</td>
<td>478</td>
</tr>
<tr>
<td>17.4.4.2</td>
<td>Elastic and Plastic Adhesive Behavior</td>
<td>479</td>
</tr>
<tr>
<td>17.4.4.3</td>
<td>Temperature and Moisture Effects</td>
<td>487</td>
</tr>
<tr>
<td>17.4.4.4</td>
<td>Joint Adherend Effects: Stiffness Imbalance and Thermal Mismatch</td>
<td>488</td>
</tr>
<tr>
<td>17.4.5</td>
<td>Recommended Joint Overlaps and Simplistic Analysis</td>
<td>492</td>
</tr>
<tr>
<td>17.4.5</td>
<td>Adhesive Peel Stress and Displacement</td>
<td>494</td>
</tr>
<tr>
<td>17.4.6</td>
<td>Durability: Fatigue, Creep, and Environmental Effects</td>
<td>502</td>
</tr>
<tr>
<td>17.4.7</td>
<td>Bonded Joint Repair Considerations</td>
<td>504</td>
</tr>
<tr>
<td>17.4.8</td>
<td>Bonded Joint Repair Design Recommendations</td>
<td>504</td>
</tr>
<tr>
<td>17.5</td>
<td>Mechanically Fastened Joints</td>
<td>505</td>
</tr>
<tr>
<td>17.5.1</td>
<td>Introduction to Mechanically Fastened Joints</td>
<td>505</td>
</tr>
<tr>
<td>17.5.2</td>
<td>Fastened Laminate Failure Modes</td>
<td>506</td>
</tr>
<tr>
<td>17.5.3</td>
<td>Fastener Failure Modes</td>
<td>509</td>
</tr>
<tr>
<td>17.5.4</td>
<td>Open-Hole Stress Concentrations: Composites Versus Metals</td>
<td>509</td>
</tr>
<tr>
<td>17.5.5</td>
<td>Loading of Mechanically Fastened Joints</td>
<td>510</td>
</tr>
<tr>
<td>17.5.6</td>
<td>Loaded Fastener Holes</td>
<td>513</td>
</tr>
<tr>
<td>17.5.7</td>
<td>Fastener Load Distribution and Joint Geometry</td>
<td>514</td>
</tr>
<tr>
<td>17.5.8</td>
<td>Lay-Up Orientation for Fastened Joints</td>
<td>518</td>
</tr>
<tr>
<td>17.5.9</td>
<td>Pad-Ups and Hybrid Material Application</td>
<td>518</td>
</tr>
<tr>
<td>17.5.10</td>
<td>Fatigue of Fastened Composite Joints</td>
<td>519</td>
</tr>
<tr>
<td>17.5.11</td>
<td>Effects of Gaps and Shims</td>
<td>520</td>
</tr>
<tr>
<td>17.5.12</td>
<td>Fastener Selection</td>
<td>521</td>
</tr>
<tr>
<td>17.5.13</td>
<td>Mechanically Fastened Repairs in Sandwich Panels</td>
<td>524</td>
</tr>
<tr>
<td>17.5.14</td>
<td>Fastened Joint Repair Recommendations</td>
<td>524</td>
</tr>
</tbody>
</table>

References | 527  |
Bibliography | 529  |
About the Authors | 531  |
Index | 533  |