

# **The Effects of UV Light and Weather**

**on Plastics and Elastomers**

**Second Edition**

**Liesl K. Massey**

# Table of Contents

---

|                                                                                   |      |
|-----------------------------------------------------------------------------------|------|
| <b>Preface</b> .....                                                              | xv   |
| <b>List of Graphs and Tables</b> .....                                            | xvii |
| <b>Introduction</b> .....                                                         | 1    |
| How to Use This Book .....                                                        | 1    |
| Weatherability .....                                                              | 1    |
| Weather Defined .....                                                             | 1    |
| Variations in Natural Weathering .....                                            | 1    |
| Testing for Weatherability .....                                                  | 1    |
| Elements of Weather .....                                                         | 2    |
| Radiation .....                                                                   | 2    |
| Wavelength Regions of UV Radiation .....                                          | 2    |
| Moisture .....                                                                    | 3    |
| Radiation and Water .....                                                         | 3    |
| Radiation and Oxygen .....                                                        | 3    |
| Reducing the Effect of Radiation .....                                            | 3    |
| Surface Temperature and Thermal Degradation .....                                 | 4    |
| Material Properties Post-Exposure .....                                           | 4    |
| UV Additives and Stabilizers .....                                                | 5    |
| UV Absorbers .....                                                                | 6    |
| Hindered Amine Light Stabilizers .....                                            | 6    |
| Antioxidants .....                                                                | 6    |
| UV Inhibitors .....                                                               | 6    |
| <b>Test Environments</b> .....                                                    | 7    |
| Indoor and Interior Exposure .....                                                | 7    |
| Outdoor Testing .....                                                             | 7    |
| Accelerated Outdoor Tests .....                                                   | 8    |
| Conventional Aging .....                                                          | 8    |
| Conventional Aging with Spray .....                                               | 8    |
| Humidity Variations .....                                                         | 9    |
| Solar Radiation .....                                                             | 9    |
| Sample Mounting Direction .....                                                   | 9    |
| Artificial Accelerated Tests .....                                                | 9    |
| Conditions for Reproducing Natural Weathering Stresses<br>in the Laboratory ..... | 9    |
| Xenon Arc .....                                                                   | 10   |
| Fluorescent or QUV .....                                                          | 10   |
| Carbon Arc or Fadeometer .....                                                    | 11   |
| Test Results .....                                                                | 11   |
| Notes on Variability in Testing and Results .....                                 | 11   |
| Color Stability .....                                                             | 12   |

## Thermoplastics

### ABS

|                                                       |           |
|-------------------------------------------------------|-----------|
| <b>Acrylonitrile-Butadiene-Styrene—Chapter 1</b>      | <b>13</b> |
| Weathering Properties                                 | 13        |
| Stabilization                                         | 13        |
| Weathering Properties by Material Supplier Trade Name | 14        |

|                                                                                              |           |
|----------------------------------------------------------------------------------------------|-----------|
| <b>Acrylonitrile-Styrene-Acrylate/Acrylonitrile-Butadiene-Styrene<br/>Capstock—Chapter 2</b> | <b>33</b> |
| Weathering Properties                                                                        | 33        |
| Weathering Properties by Material Supplier Trade Name                                        | 33        |

### Acetal

|                                                       |           |
|-------------------------------------------------------|-----------|
| <b>Acetal—Chapter 3</b>                               | <b>35</b> |
| Weathering Properties: General                        | 35        |
| Weathering Properties: Colored Material               | 35        |
| Weathering Properties: Unpigmented Material           | 36        |
| Weathering Properties: Elevated Air Temperature       | 36        |
| Weathering Properties by Material Supplier Trade Name | 37        |

### Acrylonitrile-Styrene-Acrylate

|                                                       |           |
|-------------------------------------------------------|-----------|
| <b>Acrylonitrile-Styrene-Acrylate—Chapter 4</b>       | <b>47</b> |
| Weathering Properties                                 | 47        |
| Degree of Discoloration                               | 47        |
| Thermal Resistance                                    | 47        |
| Weathering Properties by Material Supplier Trade Name | 48        |

### Acrylic

|                                                             |           |
|-------------------------------------------------------------|-----------|
| <b>Acrylic and Acrylic Copolymer—Chapter 5</b>              | <b>57</b> |
| Weathering Properties                                       | 57        |
| Weathering Properties by Material Supplier Trade Name       | 58        |
| <b>Acrylic and Polyvinyl Chloride Coextrusion—Chapter 6</b> | <b>65</b> |
| Weathering Properties                                       | 65        |

### Cellulosic Plastic

|                                                       |           |
|-------------------------------------------------------|-----------|
| <b>Cellulose Acetate Butyrate—Chapter 7</b>           | <b>67</b> |
| Weathering Properties                                 | 67        |
| Color Retention                                       | 67        |
| Weathering Properties by Material Supplier Trade Name | 68        |

## Fluoropolymers

|                                                                  |           |
|------------------------------------------------------------------|-----------|
| <b>Fluoropolymers: Overview—Chapter 8</b> .....                  | <b>71</b> |
| Fluoropolymer Weathering .....                                   | 71        |
| <b>Polytetrafluoroethylene (PTFE or TFE)—Chapter 9</b> .....     | <b>73</b> |
| Weathering Properties .....                                      | 73        |
| Weathering Properties by Material Supplier Trade Name .....      | 73        |
| <b>Fluorinated Ethylene Propylene (FEP)—Chapter 10</b> .....     | <b>75</b> |
| Weathering Properties .....                                      | 75        |
| Weathering Properties by Material Supplier Trade Name .....      | 75        |
| <b>Perfluoroalkoxy (PFA and MFA)—Chapter 11</b> .....            | <b>79</b> |
| Weathering Properties .....                                      | 79        |
| <b>Polyvinylidene Fluoride (PVDF)—Chapter 12</b> .....           | <b>81</b> |
| Weathering Properties .....                                      | 81        |
| <b>Polychlorotrifluoroethylene (PCTFE)—Chapter 13</b> .....      | <b>87</b> |
| <b>Ethylene-chlorotrifluoroethylene (ECTFE)—Chapter 14</b> ..... | <b>91</b> |
| Weathering Properties .....                                      | 91        |
| <b>Ethylene-tetrafluoroethylene (ETFE)—Chapter 15</b> .....      | <b>95</b> |
| Weathering Properties .....                                      | 95        |
| <b>Polyvinyl Fluoride (PVF)—Chapter 16</b> .....                 | <b>97</b> |
| Weathering Properties .....                                      | 97        |

## Ionomer

|                                 |            |
|---------------------------------|------------|
| <b>Ionomer—Chapter 17</b> ..... | <b>103</b> |
| Weathering Properties .....     | 103        |

## Polyphenylene Oxide

|                                             |            |
|---------------------------------------------|------------|
| <b>Polyphenylene Oxide—Chapter 18</b> ..... | <b>109</b> |
| Weathering Resistance .....                 | 109        |

## Nylon

|                                               |            |
|-----------------------------------------------|------------|
| <b>Nylon: Overview—Chapter 19</b> .....       | <b>115</b> |
| Weathering Properties: General .....          | 115        |
| Weathering Properties: UV Stabilization ..... | 115        |
| Weathering Properties: Colored Material ..... | 115        |

|                                                       |            |
|-------------------------------------------------------|------------|
| <b>Nylon 6—Chapter 20</b>                             | <b>117</b> |
| Weathering Properties                                 | 117        |
| <b>Nylon 12—Chapter 21</b>                            | <b>127</b> |
| Weathering Properties                                 | 127        |
| <b>Nylon with Glass Fiber—Chapter 22</b>              | <b>133</b> |
| Weathering Properties                                 | 133        |
| <b>Nylon 66—Chapter 23</b>                            | <b>135</b> |
| Weathering Properties                                 | 135        |
| Weathering Properties: Colored Material               | 135        |
| <b>Nylon 6,6T—Chapter 24</b>                          | <b>137</b> |
| Weathering Properties                                 | 137        |
| <b>Nylon MXD6—Chapter 25</b>                          | <b>139</b> |
| <b>Polyarylamide—Chapter 26</b>                       | <b>143</b> |
| Weathering Properties                                 | 143        |
| <b>Polycarbonate</b>                                  |            |
| <b>Polycarbonate—Chapter 27</b>                       | <b>147</b> |
| Weathering Properties                                 | 147        |
| Light Transmission                                    | 148        |
| Weathering Properties: UV Stabilization               | 148        |
| Weathering Properties by Material Supplier Trade Name | 148        |
| <b>Polycarbonate Blends—Chapter 28</b>                | <b>159</b> |
| Weathering Properties                                 | 159        |
| Weathering Properties: Stabilization                  | 159        |
| Weathering Properties by Material Supplier Trade Name | 159        |
| <b>Polyester</b>                                      |            |
| <b>Polybutylene Terephthalate—Chapter 29</b>          | <b>161</b> |
| Weathering Properties                                 | 161        |
| Weathering Properties: Stabilization                  | 161        |
| Weathering Properties by Material Supplier Trade Name | 162        |
| <b>Polyethylene Terephthalate—Chapter 30</b>          | <b>167</b> |
| Weathering Properties                                 | 167        |
| Weathering Properties by Material Supplier Trade Name | 168        |

|                                                                   |            |
|-------------------------------------------------------------------|------------|
| <b>Liquid Crystal Polymers—Chapter 31</b> .....                   | <b>173</b> |
| Weathering Properties .....                                       | 173        |
| Weathering Properties by Material Supplier Trade Name .....       | 174        |
| <b>Polyarylate—Chapter 32</b> .....                               | <b>175</b> |
| Weathering Properties .....                                       | 175        |
| <br><b>Polyimide</b>                                              |            |
| <b>Polyimide—Chapter 33</b> .....                                 | <b>177</b> |
| Weathering Properties: General .....                              | 177        |
| Weathering Properties: Outer Space and Nuclear Environments ..... | 177        |
| Weathering Properties by Material Supplier Trade Name .....       | 177        |
| <b>Polyamideimide—Chapter 34</b> .....                            | <b>181</b> |
| Weathering Properties .....                                       | 181        |
| Weathering Properties by Material Supplier Trade Name .....       | 181        |
| <b>Polyetherimide—Chapter 35</b> .....                            | <b>183</b> |
| Weathering Properties .....                                       | 183        |
| Weathering Properties by Material Supplier Trade Name .....       | 183        |
| <br><b>Polyketone</b>                                             |            |
| <b>Polyetheretherketone (PEEK)—Chapter 36</b> .....               | <b>185</b> |
| Weathering Properties .....                                       | 185        |
| <br><b>Polyolefin</b>                                             |            |
| <b>Polyethylene: Overview—Chapter 37</b> .....                    | <b>187</b> |
| Weathering Properties: General .....                              | 187        |
| Polyethylene Films .....                                          | 187        |
| Weathering Properties: Color Pigments .....                       | 188        |
| Weathering Properties: UV Stabilizers .....                       | 188        |
| Weathering Properties by Material Supplier Trade Name .....       | 189        |
| <b>Low Density Polyethylene—Chapter 38</b> .....                  | <b>193</b> |
| <b>High Density Polyethylene—Chapter 39</b> .....                 | <b>195</b> |
| Weathering Properties: Colored Material .....                     | 195        |
| Carbon Black .....                                                | 195        |
| White Pigments .....                                              | 195        |
| Yellow Pigments .....                                             | 195        |
| Red Pigments .....                                                | 196        |
| Orange Pigments .....                                             | 196        |
| Blue and Green Pigments .....                                     | 197        |

|                                                                 |            |
|-----------------------------------------------------------------|------------|
| Pigment Dispersion .....                                        | 197        |
| Part Thickness .....                                            | 197        |
| Weathering Properties by Material Supplier Trade Name .....     | 198        |
| <b>Ultrahigh Molecular Weight Polyethylene—Chapter 40 .....</b> | <b>211</b> |
| <b>Polyethylene Copolymers—Chapter 41 .....</b>                 | <b>213</b> |
| Weathering Properties .....                                     | 213        |
| Weathering Properties by Material Supplier Trade Name .....     | 214        |
| <b>Polypropylene—Chapter 42 .....</b>                           | <b>215</b> |
| Weathering Properties: Stabilization .....                      | 215        |
| Weathering Properties by Material Supplier Trade Name .....     | 217        |
| <b>Polymethylpentene—Chapter 43 .....</b>                       | <b>223</b> |
| Weathering Properties .....                                     | 223        |
| Weathering Properties by Material Supplier Trade Name .....     | 223        |
| <b>Polyphenylene Sulfide</b>                                    |            |
| <b>Polyphenylene Sulfide—Chapter 44 .....</b>                   | <b>225</b> |
| Weathering Properties by Material Supplier Trade Name .....     | 225        |
| <b>Polystyrene</b>                                              |            |
| <b>General Purpose Polystyrene—Chapter 45 .....</b>             | <b>227</b> |
| Weathering Properties .....                                     | 227        |
| Weathering Properties by Material Supplier Trade Name .....     | 227        |
| <b>High Impact Polystyrene—Chapter 46 .....</b>                 | <b>231</b> |
| Weathering Properties .....                                     | 231        |
| Weathering Properties by Material Supplier Trade Name .....     | 232        |
| <b>Polysulfone</b>                                              |            |
| <b>Polysulfone—Chapter 47 .....</b>                             | <b>239</b> |
| Weathering Properties .....                                     | 239        |
| Weathering Properties by Material Supplier Trade Name .....     | 239        |
| <b>Polyethersulfone—Chapter 48 .....</b>                        | <b>241</b> |
| Weathering Properties .....                                     | 241        |
| Weathering Properties by Material Supplier Trade Name .....     | 241        |

## **Styrene Acrylonitrile Copolymer**

|                                                             |            |
|-------------------------------------------------------------|------------|
| <b>Styrene-Acrylonitrile Copolymer—Chapter 49 .....</b>     | <b>243</b> |
| Weathering Properties .....                                 | 243        |
| Weathering Properties by Material Supplier Trade Name ..... | 244        |

## **Styrene Butadiene Copolymer**

|                                                        |            |
|--------------------------------------------------------|------------|
| <b>Styrene-Butadiene Copolymer—Chapter 50 .....</b>    | <b>247</b> |
| Weathering Properties .....                            | 247        |
| Indoor UV Light Resistance and Indirect Sunlight ..... | 247        |

## **Vinyl Resin**

|                                                        |            |
|--------------------------------------------------------|------------|
| <b>Polyvinyl Chloride—Chapter 51 .....</b>             | <b>249</b> |
| Weathering Properties .....                            | 249        |
| Thickness .....                                        | 249        |
| Plasticizers .....                                     | 249        |
| Additional Plasticizers .....                          | 250        |
| Stabilizers .....                                      | 251        |
| Pigments and Colorants .....                           | 251        |
| Yellowing .....                                        | 252        |
| Weathering Properties: Stabilization .....             | 252        |
| <b>Chlorinated Polyvinyl Chloride—Chapter 52 .....</b> | <b>255</b> |
| Weathering Properties .....                            | 255        |

## **Thermoplastic Blends/Alloys**

### **ABS Vinyl Resin Alloy**

|                                                      |            |
|------------------------------------------------------|------------|
| <b>ABS Polyvinyl Chloride Alloy—Chapter 53 .....</b> | <b>257</b> |
| Weathering Properties .....                          | 257        |

|                                                        |            |
|--------------------------------------------------------|------------|
| <b>Acrylic (PMMA) Polyvinyl Alloy—Chapter 54 .....</b> | <b>259</b> |
| Weathering Properties .....                            | 259        |

|                                                 |            |
|-------------------------------------------------|------------|
| <b>Polycarbonate ABS Alloy—Chapter 55 .....</b> | <b>261</b> |
| Weathering Properties .....                     | 261        |

## **Biodegradable Thermoplastic Alloys**

### **Biodegradable Polyethylene Films**

|                                                          |            |
|----------------------------------------------------------|------------|
| <b>Biodegradable Polyethylene Films—Chapter 56 .....</b> | <b>263</b> |
|----------------------------------------------------------|------------|

|                                                             |     |
|-------------------------------------------------------------|-----|
| Degradation Rate .....                                      | 263 |
| Weathering Properties by Material Supplier Trade Name ..... | 264 |

## **Starch Synthetic Resin Alloy—Chapter 57 ..... 269**

|                        |     |
|------------------------|-----|
| Biodegradability ..... | 269 |
|------------------------|-----|

### **Thermosets**

#### **Polyester**

## **Thermoset Polyester—Chapter 58 ..... 271**

|                                                             |     |
|-------------------------------------------------------------|-----|
| Polyester Powder .....                                      | 271 |
| Urethane Polyesters .....                                   | 271 |
| Weathering Properties: UV Stabilization .....               | 271 |
| Weathering Properties by Material Supplier Trade Name ..... | 272 |

#### **Polyurethane**

## **Polyurethane Reaction Injection Molding System—Chapter 59 ..... 273**

|                                                             |     |
|-------------------------------------------------------------|-----|
| Weathering Properties .....                                 | 273 |
| Weathering Properties by Material Supplier Trade Name ..... | 274 |

### **Thermoplastic Elastomers**

#### **Thermoplastic Elastomers**

## **Thermoplastic Elastomers: Overview—Chapter 60 ..... 279**

## **Chlorinate Polyethylene Elastomer—Chapter 61 ..... 281**

|                             |     |
|-----------------------------|-----|
| Weathering Properties ..... | 281 |
|-----------------------------|-----|

## **Olefinic Thermoplastic Elastomer—Chapter 62 ..... 283**

|                                                             |     |
|-------------------------------------------------------------|-----|
| Weathering Properties .....                                 | 283 |
| Outdoor Accelerated Exposure Testing .....                  | 284 |
| Weathering Properties by Material Supplier Trade Name ..... | 285 |

## **Polyester Thermoplastic Elastomer—Chapter 63 ..... 301**

|                                                             |     |
|-------------------------------------------------------------|-----|
| Weathering Properties .....                                 | 301 |
| Weathering Properties: Color Pigments .....                 | 301 |
| Weathering Properties by Material Supplier Trade Name ..... | 302 |

## **Polystyrene-Butadiene-Styrene Thermoplastic—Chapter 64 ..... 311**

|                             |     |
|-----------------------------|-----|
| Weathering Properties ..... | 311 |
|-----------------------------|-----|

## **Styrenic Thermoplastic Elastomer—Chapter 65 ..... 313**

|                             |     |
|-----------------------------|-----|
| Weathering Properties ..... | 313 |
|-----------------------------|-----|

|                                                             |     |
|-------------------------------------------------------------|-----|
| Weathering Properties: Stabilization .....                  | 313 |
| Weathering Properties by Material Supplier Trade Name ..... | 314 |

## **Urethane Thermoplastic Elastomer—Chapter 66 .....** **315**

|                                                             |     |
|-------------------------------------------------------------|-----|
| Weathering Properties .....                                 | 315 |
| Weathering Properties: UV Stabilization .....               | 316 |
| Weathering Properties by Material Supplier Trade Name ..... | 317 |

## **Nitrile Thermoplastic Elastomers—Chapter 67 .....** **323**

|                                                             |     |
|-------------------------------------------------------------|-----|
| Weathering Properties .....                                 | 323 |
| Weathering Properties by Material Supplier Trade Name ..... | 324 |

## **Thermosetting Elastomers (Rubbers)**

### **Thermoset Elastomers or Rubbers**

## **Thermoset Elastomers or Rubbers: Overview—Chapter 68 .....** **325**

## **Butyl Rubber, Bromobutyl Rubber, and Chlorobutyl Rubber—Chapter 69 .....** **327**

|                                               |     |
|-----------------------------------------------|-----|
| Weathering Properties .....                   | 327 |
| Weathering Properties: Ozone Resistance ..... | 327 |

## **Chlorosulfonated Polyethylene Rubber—Chapter 70 .....** **329**

|                                                             |     |
|-------------------------------------------------------------|-----|
| Weathering Properties .....                                 | 329 |
| Weathering Properties: Color Pigments .....                 | 329 |
| Weathering Properties: Curing Systems .....                 | 330 |
| Weathering Properties: Fillers .....                        | 331 |
| Weathering Properties: Plasticizers .....                   | 332 |
| Weathering Properties by Material Supplier Trade Name ..... | 332 |

## **Ethylene-Propylene Copolymer—Chapter 71 .....** **343**

|                                                             |     |
|-------------------------------------------------------------|-----|
| Weathering Properties .....                                 | 343 |
| Weathering Properties by Material Supplier Trade Name ..... | 343 |

## **Ethylene-Propylene Diene Methylene Terpolymer—Chapter 72 .....** **345**

|                                                                    |     |
|--------------------------------------------------------------------|-----|
| UV Resistance .....                                                | 345 |
| Outdoor Weather Resistance .....                                   | 345 |
| Accelerated Outdoor Weathering Resistance .....                    | 346 |
| Accelerated Artificial Weathering Resistance .....                 | 347 |
| Effect of Carbon Black on Weatherability .....                     | 347 |
| Effect of Color Pigments on Weatherability .....                   | 347 |
| Effective UV Screening Agents in Mineral-Filled Vulcanizates ..... | 348 |
| Effect of Curing Systems on Weatherability .....                   | 348 |
| Effect of Plasticizers on Weatherability .....                     | 348 |
| Ozone Resistance .....                                             | 348 |

## **Neoprene Rubber—Chapter 73 .....** **373**

|                                                             |     |
|-------------------------------------------------------------|-----|
| Weathering Properties .....                                 | 373 |
| Weathering Properties by Material Supplier Trade Name ..... | 374 |

|                                                                |            |
|----------------------------------------------------------------|------------|
| <b>Polybutadiene—Chapter 74</b> .....                          | <b>383</b> |
| Weathering Properties .....                                    | 383        |
| Weathering Properties by Material Supplier Trade Name .....    | 384        |
| <b>Polyisoprene Rubber—Chapter 75</b> .....                    | <b>385</b> |
| Weathering Properties .....                                    | 385        |
| Weathering Properties by Material Supplier Trade Name .....    | 386        |
| <b>Polyurethane—Chapter 76</b> .....                           | <b>391</b> |
| Weathering Properties .....                                    | 391        |
| Weathering Properties: Stabilization .....                     | 391        |
| Weathering Properties by Material Supplier Trade Name .....    | 392        |
| <b>Silicone Rubber—Chapter 77</b> .....                        | <b>393</b> |
| Weathering Properties .....                                    | 393        |
| Weathering Properties by Material Supplier Trade Name .....    | 393        |
| <b>Fluoropolymers in Coating Applications—Appendix 1</b> ..... | <b>395</b> |
| Architectural Fabrics .....                                    | 395        |
| Fabric Base Materials .....                                    | 395        |
| Fabric Coatings .....                                          | 395        |
| Fabric Top Finishes or Topcoats .....                          | 395        |
| Weathering Resistance .....                                    | 396        |
| <b>Coil Coatings—Appendix 2</b> .....                          | <b>399</b> |
| Comparative Properties and Performance Chart .....             | 399        |
| Coil Coating Topcoats .....                                    | 399        |
| <b>Glossary of Terms</b> .....                                 | <b>401</b> |
| <b>References</b> .....                                        | <b>445</b> |
| <b>Trade Name Index</b> .....                                  | <b>453</b> |
| <b>Plastics Design Library</b> .....                           | <b>455</b> |