Polymer–Graphene Nanocomposites

Edited by

Vikas Mittal
The Petroleum Institute, Chemical Engineering Program, Abu Dhabi,
United Arab Emirates
Email: vmittal@pi.ac.ae
## Contents

Chapter 1  Graphene Functionalization: A Review  
*Mo Song and Dongyu Cai*

1.1 Introduction  
1.2 Fabrication of Graphene  
  1.2.1 Mechanical Cleavage  
  1.2.2 Reduction of Graphene Oxide  
  1.2.3 Chemical Vapour Deposition  
  1.2.4 Synthesis of Graphene Nanoribbons (GNRs)  
  1.2.5 Other Methods  
1.3 Functionalization of Graphene  
  1.3.1 Functionalization of Graphene with Organic Species  
  1.3.2 Functionalization of Graphene with Macromolecules  
  1.3.3 Functionalization of Graphene with Inorganic Nanoparticles (INPs)  
1.4 Functionalized Graphene–Polymer Nanocomposites (FPNs)  
  1.4.1 Fabrication  
  1.4.2 Mechanical Properties  
  1.4.3 Electrical Properties  
  1.4.4 Thermal Properties  
1.5 Conclusions and Perspective  
References

---

RSC Nanoscience & Nanotechnology No. 26  
Polymer–Graphene Nanocomposites  
Edited by Vikas Mittal  
© The Royal Society of Chemistry 2012  
Published by the Royal Society of Chemistry, www.rsc.org
Chapter 2  Gelation of Graphene Oxide

Gaoquan Shi

2.1 Introduction  52
2.2 GO-Based Gels  53
  2.2.1 Acid-Induced Gelation  53
  2.2.2 Cross-linker-Induced Gelation  55
2.3 Reduced GO-Based Gels  60
  2.3.1 Hydrothermal or Solvothermal Reduction  60
  2.3.2 Chemical Reduction  62
  2.3.3 Electrochemical Reduction  62
2.4 Conclusion  63
Acknowledgements  63
References  63

Chapter 3  Electrically Conductive Polymer–Graphene Composites
Prepared Using Latex Technology

Nadia Grossiord, Marie-Claire Hermant and Evgeniy Tkalya

3.1 Introduction  66
3.2 Fundamentals of Latex Technology  67
  3.2.1 In Situ Polymerization and Heterocoagulation Strategies  70
3.3 Graphene–Polymer Composites via Latex Technology  72
3.4 Graphene–Polymer Composite Production: An Overview  75
3.5 Industrial Relevance  76
3.6 Conclusion  81
References  82

Chapter 4  Polymer–Graphene Nanocomposites by Living Polymerization (RAFT) in Miniemulsion

Hussein M. Etmimi and Ron D. Sanderson

4.1 Introduction  86
4.2 Synthesis of PGNs Based on Functionalized Graphene  87
4.3 Miniemulsion Polymerization  89
  4.3.1 Miniemulsion Versus Emulsion Polymerization  90
  4.3.2 Typical Miniemulsion Formulations  91
  4.3.3 Preparation of Miniemulsions  92
  4.3.4 Initiators Used in Miniemulsions  93
  4.3.5 Miniemulsion Polymerization for the Synthesis of PGNs  94
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.4</td>
<td>Conventional Free Radical Polymerization <em>Versus</em> Controlled/Living Radical Polymerization</td>
<td>95</td>
</tr>
<tr>
<td>4.5</td>
<td>Fundamentals of CLRP</td>
<td>96</td>
</tr>
<tr>
<td>4.6</td>
<td>Common CLRP Techniques</td>
<td>97</td>
</tr>
<tr>
<td>4.6.1</td>
<td>NMP</td>
<td>97</td>
</tr>
<tr>
<td>4.6.2</td>
<td>ATRP</td>
<td>98</td>
</tr>
<tr>
<td>4.6.3</td>
<td>RAFT-Mediated Polymerization</td>
<td>99</td>
</tr>
<tr>
<td>4.7</td>
<td>RAFT-Mediated Emulsion Polymerization <em>Versus</em> Miniemulsion Polymerization</td>
<td>100</td>
</tr>
<tr>
<td>4.8</td>
<td>Synthesis of PGNs Using the RAFT Process in Miniemulsion</td>
<td>101</td>
</tr>
<tr>
<td>4.9</td>
<td>Characterization of PGNs Synthesized by the RAFT Method</td>
<td>103</td>
</tr>
<tr>
<td>4.9.1</td>
<td>FT-IR and Solubility Analysis</td>
<td>103</td>
</tr>
<tr>
<td>4.9.2</td>
<td>TEM Analysis</td>
<td>105</td>
</tr>
<tr>
<td>4.9.3</td>
<td>XRD Analysis</td>
<td>106</td>
</tr>
<tr>
<td>4.9.4</td>
<td>SEC Analysis</td>
<td>107</td>
</tr>
<tr>
<td>4.9.5</td>
<td>Mechanical Properties</td>
<td>108</td>
</tr>
<tr>
<td>4.9.6</td>
<td>Thermal Stability</td>
<td>110</td>
</tr>
<tr>
<td>4.10</td>
<td>Conclusions</td>
<td>111</td>
</tr>
<tr>
<td>References</td>
<td></td>
<td>112</td>
</tr>
</tbody>
</table>

**Chapter 5** *In Situ* Polymerization in the Presence of Graphene

*Yuan Hu and Chenlu Bao*

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1</td>
<td>Introduction</td>
<td>117</td>
</tr>
<tr>
<td>5.2</td>
<td>Polyaniline (PANI)</td>
<td>118</td>
</tr>
<tr>
<td>5.3</td>
<td>Polypyrrole (PPy)</td>
<td>121</td>
</tr>
<tr>
<td>5.4</td>
<td>Epoxy</td>
<td>124</td>
</tr>
<tr>
<td>5.5</td>
<td>Poly(methyl methacrylate) (PMMA)</td>
<td>125</td>
</tr>
<tr>
<td>5.6</td>
<td>Polystyrene (PS)</td>
<td>126</td>
</tr>
<tr>
<td>5.7</td>
<td>Polyurethane (PU)</td>
<td>130</td>
</tr>
<tr>
<td>5.8</td>
<td>Other Polymers</td>
<td>131</td>
</tr>
<tr>
<td>5.9</td>
<td>Summary</td>
<td>132</td>
</tr>
<tr>
<td>References</td>
<td></td>
<td>132</td>
</tr>
</tbody>
</table>

**Chapter 6** Microstructure and Properties of Compatibilized Polyethylene–Graphene Oxide Nanocomposites

*A. U. Chaudhry, Vikas Mittal and N. B. Matsko*

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1</td>
<td>Introduction</td>
<td>141</td>
</tr>
<tr>
<td>6.2</td>
<td>Experimental</td>
<td>144</td>
</tr>
<tr>
<td>6.2.1</td>
<td>Materials</td>
<td>144</td>
</tr>
</tbody>
</table>
6.2.2 Preparation of Graphite Oxide and Graphene Oxide 144
6.2.3 Nanocomposite Generation 145
6.2.4 Material Characterization 145
6.3 Results and Discussion 146
6.4 Conclusions 159
Acknowledgements 159
References 159

Chapter 7 pH-Sensitive Graphene–Polymer Nanocomposites 162
Jingquan Liu and Thomas P. Davis

7.1 Introduction 162
7.2 Preparation of Graphene–Polymer Nanocomposites 164
  7.2.1 Covalent Bonding 164
  7.2.2 Non-Covalent Interactions 165
7.3 Applications of pH-Sensitive Graphene Polymer Nanocomposites 167
  7.3.1 Sensors and Detection Devices 167
  7.3.2 Catalysis and Cells 170
  7.3.3 Supercapacitors 171
  7.3.4 Drug Delivery 172
  7.3.5 Others 173
7.4 Conclusions and Perspectives 174
Acknowledgement 174
References 174

Chapter 8 Dispersible Graphene Oxide–Polymer Nanocomposites 179
Gang Liu, Koon-Gee Neoh and En-Tang Kang

8.1 Introduction 179
8.2 Covalently Functionalized Graphene Oxide–Polymer Nanocomposites 180
8.3 The ‘Grafting from’ Approach 182
8.4 The ‘Grafting to’ Approach 189
8.5 Non-Covalent Functionalization of Graphene Oxide Nanosheets 196
8.6 Summary and Future Challenges 203
References 204
Chapter 9  Graphene–Conducting Polymer Nanocomposites Prepared by Interfacial Polymerization  211
Sergio H. Domingues, Rodrigo V. Salvatierra and Aldo J.G. Zarbin

9.1 Introduction  211
9.2 Conducting Polymers  212
  9.2.1 Polyaniline (PANI)  213
9.3 Graphene–Polyaniline Nanocomposites  214
9.4 Graphene–Polyaniline Nanocomposites Through Interfacial Polymerization  215
9.5 Conclusion and Final Remarks  223
References  224

Chapter 10  Crystallization Properties of Isotactic Polypropylene–Graphene Nanocomposites  227
Jia-Zhuang Xu, Zhong-Ming Li and Benjamin S. Hsiao

10.1 Introduction  227
10.2 Intrachain Conformational Ordering of iPP–Graphene Nanocomposites  229
10.3 Crystallization Kinetics of iPP–Graphene Nanocomposites Under Shear Flow  235
  10.3.1 Crystallization Under Quiescent Conditions  235
  10.3.2 Crystallization Under Shear Flow  236
  10.3.3 Combined Effect of GNSs and Shear Flow on Crystallization of iPP  245
10.4 Summary  249
Acknowledgement  249
References  249

Subject Index  252