

# Contents

**Preface — V**

**Acknowledgments — VII**

**A note on sources — XVII**

## **1 Introduction — 1**

- 1.1 History of composite materials — 1
- 1.2 What are composite materials? — 2
  - 1.2.1 Engineered composites — 3
- 1.3 Types of composites — 3
  - 1.3.1 Composite resins with rice hulls — 3
  - 1.3.2 Composite profiles with rice hulls — 4
  - 1.3.3 Wood polymer composites — 4
  - 1.3.4 High-density polyethylene resin composites with rice hulls — 5
  - 1.3.5 Polymer composites with recycled plastics — 5
  - 1.3.6 Fibre-reinforced polymers — 5
  - 1.3.7 Concrete — 5
  - 1.3.8 Shape-polymer composites — 6
  - 1.3.9 Metal fibre composites — 6
  - 1.3.10 Thermoplastic composites with metal powders — 6
  - 1.3.11 Structured composites — 7
  - 1.3.12 Natural composite – wood — 7
- 1.4 Uses for composites — 7
  - 1.4.1 Polymeric composite resins in injection moulding — 7
  - 1.4.2 Polymeric composite resins in extrusion — 8
  - 1.4.3 Polymeric composites in compression moulding — 8
  - 1.4.4 Some widely used applications for composites — 8
- 1.5 Why use thermoplastic bio-composites? — 9

## **2 Basic technology of plastics — 11**

- 2.1 Introduction to plastics — 11
- 2.2 Chemistry of plastics — 11
  - 2.2.1 The atom — 12
  - 2.2.2 Molecular weight (Mass) — 12
  - 2.2.3 Polymeric molecules — 13
  - 2.2.4 Polymers — 14
  - 2.2.5 Polymerisation — 14
  - 2.2.6 Polymer structures — 15
  - 2.2.7 Morphological structures — 16

|          |                                                              |           |
|----------|--------------------------------------------------------------|-----------|
| 2.2.8    | Polymer blends —                                             | 17        |
| 2.2.9    | Filled polymers —                                            | 18        |
| 2.2.10   | Modified polymers —                                          | 18        |
| 2.2.11   | Polymer groups —                                             | 18        |
| 2.3      | Properties of plastics —                                     | 19        |
| 2.3.1    | Compatibility of material properties —                       | 20        |
| 2.3.2    | Mechanical properties —                                      | 20        |
| 2.3.3    | Friction and wear —                                          | 20        |
| 2.3.4    | Environmental effects —                                      | 21        |
| 2.3.5    | Water absorption —                                           | 21        |
| 2.3.6    | Weathering effects —                                         | 21        |
| 2.4      | Moulding process for plastics —                              | 22        |
| 2.5      | Recycling of plastics —                                      | 23        |
| <b>3</b> | <b>Composite technology —</b>                                | <b>25</b> |
| 3.1      | Principles of composites —                                   | 25        |
| 3.1.1    | Principles of polymeric composite resins —                   | 26        |
| 3.1.2    | Principles of polymeric composite extruded profiles —        | 26        |
| 3.1.3    | Principles of polymeric composites in injection moulding —   | 27        |
| 3.1.4    | Principles of polymeric composites in compression moulding — | 27        |
| 3.2      | Formation of composites —                                    | 28        |
| 3.2.1    | Extrusion —                                                  | 28        |
| 3.2.2    | Matched die —                                                | 29        |
| 3.2.3    | Hand layup processing —                                      | 30        |
| 3.2.4    | Spray-up processing —                                        | 30        |
| 3.2.5    | Rigid vacuum forming —                                       | 31        |
| 3.2.6    | Vacuum-bag process —                                         | 31        |
| 3.2.7    | Pressure-bag processing —                                    | 32        |
| 3.2.8    | Filament winding process —                                   | 32        |
| 3.2.9    | Centrifugal reinforcing —                                    | 33        |
| 3.2.10   | Pultrusion —                                                 | 33        |
| 3.2.11   | Cold stamp forming —                                         | 33        |
| 3.3      | General properties of composites —                           | 34        |
| 3.3.1    | Density —                                                    | 34        |
| 3.3.2    | Compressive strength —                                       | 35        |
| 3.3.3    | Impact strength —                                            | 35        |
| 3.3.4    | Permeability and sorption —                                  | 35        |
| 3.3.5    | Weathering —                                                 | 36        |
| 3.3.6    | Water absorption —                                           | 36        |
| 3.3.7    | Friction and wear —                                          | 36        |
| 3.3.8    | Fatigue —                                                    | 37        |
| 3.3.9    | Aesthetic properties —                                       | 37        |

**4 Common polymers and additives used for processing — 39**

- 4.1 Polyethylene — 39
  - 4.1.1 Physical properties — 40
  - 4.1.2 Chemical properties — 40
  - 4.1.3 Classifications — 40
- 4.2 Polypropylene — 41
  - 4.2.1 Chemical and physical properties — 41
- 4.3 Polyvinyl chloride — 42
  - 4.3.1 Production — 42
  - 4.3.2 Additives for polymers — 43
  - 4.3.3 Plasticisers — 43
  - 4.3.4 Important properties — 43
- 4.4 Polystyrene — 44
  - 4.4.1 Structure of polystyrene — 44
  - 4.4.2 Polymerisation — 44
- 4.5 High-density polyethylene — 45
  - 4.5.1 Properties — 45
- 4.6 Acrylonitrile-butadiene-styrene — 46
  - 4.6.1 Properties — 46
- 4.7 Polymer additives — 46
  - 4.7.1 Anti-blocking agents — 47
  - 4.7.2 Slip additives — 47
  - 4.7.3 Plasticisers — 48
  - 4.7.4 Stabilisers — 48
  - 4.7.5 Antioxidants — 48
  - 4.7.6 Flame retardants — 48
  - 4.7.7 Ultraviolet stabilisers — 49
  - 4.7.8 Antistatic agents — 49
  - 4.7.9 Antimicrobial agents — 50
  - 4.7.10 Blowing agents — 50
  - 4.7.11 Colourants — 51
  - 4.7.12 Fillers — 51

**5 Rice hulls for composites — 53**

- 5.1 Introduction — 53
- 5.2 Properties of rice hulls — 53
- 5.3 Chemistry of rice hulls — 55
- 5.4 Uses for rice hulls — 56
  - 5.4.1 Extrusion, injection moulding and compression moulding — 56
  - 5.4.2 Animal feed industry — 57
  - 5.4.3 Lumber from composites — 57
  - 5.4.4 Building materials — 57

|          |                                                           |           |
|----------|-----------------------------------------------------------|-----------|
| 5.4.5    | Production of glass —                                     | 58        |
| 5.4.6    | Rice hulls ash in road building —                         | 58        |
| 5.4.7    | Fuel for steam boilers —                                  | 58        |
| 5.4.7.1  | Case study —                                              | 59        |
| 5.4.8    | Rice hulls in fertilisers —                               | 59        |
| 5.4.9    | Rice hulls in cement bricks —                             | 60        |
| 5.4.10   | Rice hull briquettes —                                    | 60        |
| 5.4.11   | Rice hull ash —                                           | 61        |
| 5.4.12   | Case in point —                                           | 61        |
| 5.4.13   | Rice hulls in building construction —                     | 62        |
| 5.4.14   | Miscellaneous uses —                                      | 62        |
| <b>6</b> | <b>Polymeric composites with different constituents —</b> | <b>63</b> |
| 6.1      | What are wood plastics composites? —                      | 63        |
| 6.1.1    | General properties of wood plastic composites —           | 63        |
| 6.1.2    | Technology of wood plastic composites – the basics —      | 64        |
| 6.1.3    | Market potential for wood plastic composites —            | 66        |
| 6.2      | Role of polymers —                                        | 68        |
| 6.2.1    | Variations in polymer matrices —                          | 69        |
| 6.3      | Production of wood plastic composites —                   | 70        |
| 6.4      | General applications for wood plastic composites —        | 71        |
| 6.5      | Long fibre-reinforced thermoplastics —                    | 72        |
| 6.6      | Polymeric composites with other fibres —                  | 73        |
| <b>7</b> | <b>Important stages of the production process —</b>       | <b>75</b> |
| 7.1      | Reduction of particle size —                              | 75        |
| 7.1.1    | Equipment used for reduction of particle size —           | 76        |
| 7.2      | Drying of rice hulls —                                    | 77        |
| 7.2.1    | Bulk drying systems —                                     | 78        |
| 7.2.2    | Summary —                                                 | 79        |
| 7.3      | Mixing and compounding —                                  | 80        |
| 7.3.1    | Industrial mixers —                                       | 80        |
| 7.4      | Single-screw compounders —                                | 80        |
| 7.5      | Twin-screw compounders —                                  | 81        |
| 7.5.1    | Basic characteristics —                                   | 81        |
| 7.5.2    | Co-rotating intermeshing extruders —                      | 82        |
| 7.5.3    | Counter-rotating non-intermeshing extruders —             | 83        |
| 7.5.4    | Continuous mixers —                                       | 84        |
| 7.6      | Pelletising of polymeric composites —                     | 84        |
| 7.7      | Processing of polymeric composites by extrusion —         | 85        |
| 7.8      | Extrusion guidelines —                                    | 86        |
| 7.8.1    | Extrusion screws —                                        | 87        |

- 7.8.2 Melt temperature — 87
- 7.8.3 Temperature settings — 87
- 7.8.4 Extruder warm-up — 88
- 7.8.5 Heat supply — 88
- 7.8.6 Die heaters — 88

## **8 Colouring of polymers and composites — 93**

- 8.1 Introduction — 93
  - 8.1.1 Theory of colours — 93
  - 8.1.2 Colour wheel — 94
  - 8.1.3 Primary colours — 94
  - 8.1.4 Secondary colours — 94
  - 8.1.5 Tertiary colours — 95
  - 8.1.6 Warm and cool colours — 95
  - 8.1.7 Tints, shades and tones — 95
  - 8.1.8 Colour harmonies — 95
- 8.2 Masterbatches — 96
- 8.3 Liquid and solid colourants for polymer composites — 96
- 8.4 Methods of colouring polymers — 98
  - 8.4.1 Masterbatch concentrates — 98
  - 8.4.2 Cube blends — 98
  - 8.4.3 Pre-coloured polymer resins — 98
- 8.5 Universal masterbatches — 99
- 8.6 Custom colours for polymers — 99

## **9 Manufacturing of polymeric composite resins — 101**

- 9.1 Concept — 101
- 9.2 Manufacturing process in brief — 101
- 9.3 Raw materials — 102
  - 9.3.1 Polymers — 102
  - 9.3.2 Rice hulls — 102
  - 9.3.3 Additives — 104
- 9.4 Processing machinery and equipment — 104
  - 9.4.1 Co-rotating twin-screw extrusion/pelletising line — 105
  - 9.4.2 Specifications — 105

## **10 Polymeric composites with rice hulls for extrusion — 109**

- 10.1 Concept — 109
- 10.2 Production of additives for polymeric composites with rice hulls — 109
  - 10.2.1 Coupling agents — 110
  - 10.2.2 Lubricants — 110

|           |                                                                            |
|-----------|----------------------------------------------------------------------------|
| 10.2.3    | Colourants — 111                                                           |
| 10.2.4    | Chemical foaming — 111                                                     |
| 10.2.5    | Countering mould and mildew — 112                                          |
| 10.2.6    | Fillers — 112                                                              |
| 10.3      | Extrusion of polymeric composites with rice hulls — 113                    |
| 10.4      | Extrusion systems for polymeric composites with rice hulls — 114           |
| 10.5      | End applications of products of polymeric composites with rice hulls — 116 |
| <b>11</b> | <b>Polymeric composite resins in injection moulding — 121</b>              |
| 11.1      | Introduction to injection moulding — 121                                   |
| 11.2      | Injection moulding machine — 121                                           |
| 11.3      | Polymer resins for injection moulding — 122                                |
| 11.4      | Injection moulding process — 123                                           |
| 11.5      | Guidelines for injection moulding with composite resins — 124              |
| 11.6      | Selection of polymeric composite resins — 125                              |
| 11.6.1    | Moisture content — 126                                                     |
| 11.6.2    | Pellet characteristics — 126                                               |
| 11.6.3    | Correct grades — 126                                                       |
| 11.7      | Recommended processing guidelines — 126                                    |
| 11.7.1    | Causes for rejection of parts in injection moulding — 127                  |
| <b>12</b> | <b>Polymeric composite resins in compression moulding — 129</b>            |
| 12.1      | Uses of rice hull ash — 129                                                |
| 12.1.1    | Steel industry — 129                                                       |
| 12.1.2    | Cement industry — 129                                                      |
| 12.1.3    | Other uses — 130                                                           |
| 12.1.4    | Rice hull ash in road building — 130                                       |
| 12.2      | What is compression moulding? — 131                                        |
| 12.3      | Brief history of compression moulding — 132                                |
| 12.4      | Raw materials for compression moulding — 132                               |
| 12.4.1    | Thermoplastic polymeric composite resins — 132                             |
| 12.4.2    | Thermosetting polymeric composite resins — 132                             |
| 12.5      | Dangers and safety information — 133                                       |
| 12.6      | Compression-moulded products — 133                                         |
| 12.6.1    | Compression moulding in the automotive industry — 134                      |
| 12.6.2    | Compression moulding in the construction industry — 134                    |
| 12.6.3    | Compression moulding in the consumer sector — 134                          |
| 12.6.4    | Compression moulding in the food services sector — 135                     |
| 12.6.5    | Compression moulding in the industrial sector — 135                        |
| 12.6.6    | Compression moulding in the medical sector — 135                           |

**Abbreviations — 137**

**Glossary — 139**

**Appendix 1 Conversion table of units commonly used in industry — 147**

**Appendix 2 Suppliers of polymers, additives, machinery and rice hulls — 150**

A2.1 Polymer suppliers — 150

A2.2 Suppliers of additives — 150

A2.3 Suppliers of machinery — 151

A2.4 Suppliers of rice hulls — 151

**Index — 153**