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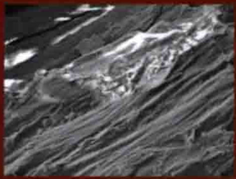
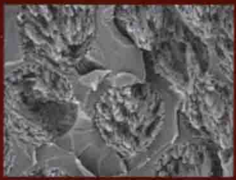
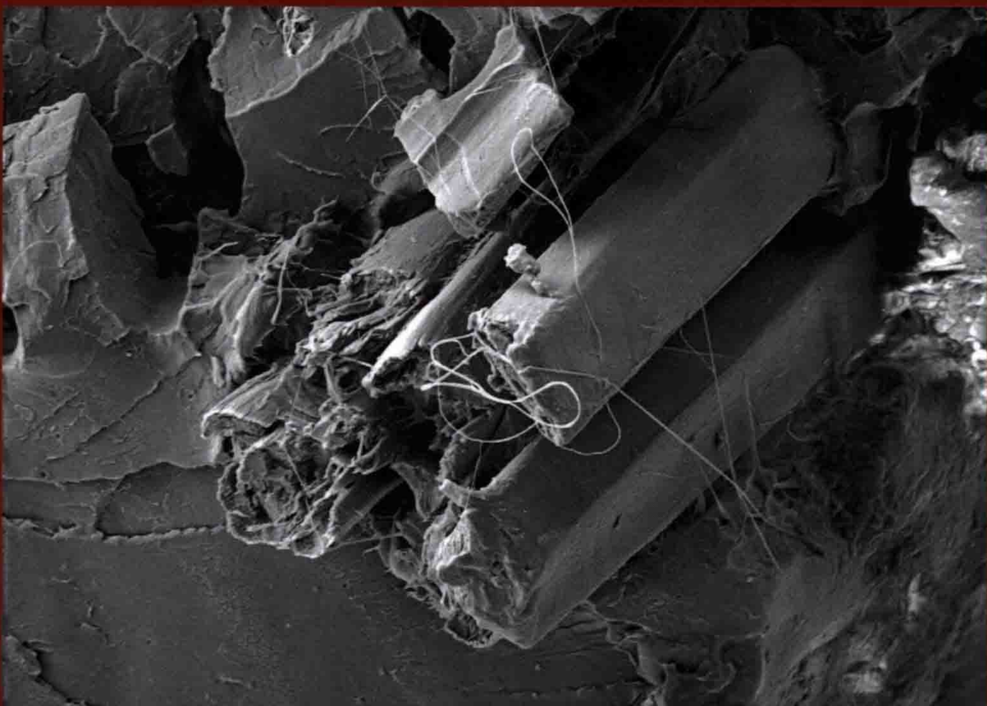




Biocomposites for High-Performance Applications

Current Barriers and Future Needs Towards Industrial Development

Edited by Dipa Ray



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WOODHEAD PUBLISHING SERIES IN COMPOSITES SCIENCE AND ENGINEERING

Biocomposites developed from renewable resources have received significant interest in recent years due to increased awareness of a more environmentally sustainable society. Although biocomposites have emerged as an alternative to glass fibre composites in many applications, they have been mostly perceived as low-performance materials. Significant technological advancements are required in terms of their supply, consistency, and manufacturability to improve their performance and reliability. This book presents a comprehensive review of various aspects of biocomposites from the existing literature and discusses the drawbacks associated with such products. The chapters in this book have described:

- Different cellulose based reinforcement types: plant derived and man-made;
- Biomatrices- thermoplastic biopolymers and thermosetting bioresins; their comparison with equivalent synthetic counterparts in regard to their processing and performance;
- Forensic identification techniques of bast fibres;
- Fibre matrix interface and environmental degradation behaviour;
- In-situ compatibilization and reactive extrusion of biocomposites and their rapid manufacturing possibilities;
- Recent innovations in biocomposites and their possible use in aerospace sector.

This book includes contributions from renowned experts in biocomposite field. The novelty of this book lies in the fact that it has focussed on identifying the current barriers associated with such materials and discussed the future direction. This book is a technical guide for students, engineers, and scientists in industries and academia, who will find interesting ideas for future research to develop next generation of biocomposite materials and processes for high performance applications.

Dipa Ray is Lecturer at University of Edinburgh, United Kingdom. Her main research interests are polymer composites with a special focus on biofibres, biopolymers and biocomposites. She has been the author of more than 65 papers in peer-reviewed international journals, over 30 conference proceedings and has written 12 chapters in books.

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Preface

The development of high-performance polymer composites has revolutionized our society in many ways. These materials have excellent performance and have been immensely successful over the last few decades. But their adverse effects on the environment cannot be disregarded anymore. In recent times there has been an upsurge of awareness all over the world regarding the negative influence of such materials on global warming and the environment. Intensive search is ongoing for materials that will fit into this technology footprint without harming the environment. This has lead to a growing demand for materials derived from renewable resources that are environmentally friendly, nontoxic, sustainable, and lightweight with mechanical properties equivalent to the petroleum derived ones. Biocomposites fulfil many of such criteria and comprise a very important field of research in the current scenario. Biocomposite applications are slowly increasing in rigid packaging, automotives, consumer goods, and construction industries. However, significant efforts are required to make them more competitive and to take full benefit of their eco-friendliness. A number of investigative research have been carried out in the last decades in this field, but only few of them have moved to the higher level for commercial exploitation. This book aims to identify and highlight the barriers that currently exist in the field of biocomposites, particularly in their industrial-scale development and availability as a commercial product.

It is well known that natural fibres have emerged as an alternative to glass fibres in many applications, but they have been mostly known as low-performance materials. Significant technological advancements are required in terms of their supply, consistency, and large-scale manufacturability to ameliorate them to a higher level. Man-made cellulose fibres with uniform supply and consistent property can be explored for developing high-performance sustainable biocomposites. The inherent structures of the plant fibres, which are different from that of the man-made fibres, play a significant role in the energy absorption and failure behaviour of the biocomposites. Forensic identification techniques can be utilized to generate new information on biofibres to understand their behaviour under various loading conditions. Biopolymers of various grades, derived from natural or petroleum resources, currently exist in market and are highly favoured for applications in biomedical and packaging. But most of them cannot compete with the conventional plastics in price or performance. New bioresins with renewable contents are recently appearing in market, but further research and developments are required to enhance their performance and suitability for large-scale manufacturing. Fibre-matrix bonding, which plays the key role in a composite, is generally not optimized in biocomposites to attain the highest stress transfer at the interface. For glass fibre reinforcements, standard silane coupling agents are successfully employed by the fibre manufacturers to enhance their interfacial compatibility with different polymer matrices. But no standard coupling agents or surface modification techniques have yet been identified for biofibres which can be used in industrial level to enhance their performance. There remains a huge scope of future research in this area. Environmental degradation weakens the performance of biocomposites and refrain them from high-end applications. Significant research input is required to predict their durability and identify ways to enhance their environmental resistance property. Efficient processing is another important aspect which controls the success of biocomposite products. The importance of reactive extrusion and in situ compatibilization is likely to grow in coming years to produce high-performance recyclable products. Rapid composite manufacturing techniques such as microwave processing, UV curing, or e-beam curing are now becoming popular and research in these areas can open up novel manufacturing routes for biocomposites. A study on recent innovations can give an insight on the current research trends in academia and product developments in the industries.

The present book provides a comprehensive overview of the various aspects of biocomposites as mentioned above and pinpoints the current challenges and drawbacks associated with them. Identification of the problem can only lead to a plausible solution. With that view, future research needs have been discussed in this book. I believe the information provided in this book will be interesting for both the academia and industry.

The main credit of this book goes to the authors of the chapters for putting together all the valuable information, finding the current challenges, and applying their experience and knowledge to identify the future research needs. Finally I would like to thank all the authors who contributed in this book as well as the Elsevier Publishing staff who helped enormously in making this book possible.

D. Ray

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Plant fibre reinforcements

1

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1.1 Introduction

Biocomposites have received considerable interest in recent years due to increased environmental awareness, concerns regarding the depletion of fossil fuels, increased drive towards sustainable technologies, and European reindustrialization based on the development of Bio-economy. The consumption of fibre-reinforced plastics (FRPs) in our daily lives is enormous and this lead to the global production of these materials up to 5.9 million ton in 1999, whereas in 2011, it reached up to 8.7 million ton [1]. Excellent mechanical properties make them suitable for high-performance applications such as automotives and aircrafts. But with the increasing use of FRPs, environmental issues like nonrecyclability and land fillings are also increasing day by day. To reduce these problems, interests are growing for the use of bioresources in FRPs instead of synthetic ones. Use of plant fibres in FRPs is a major effort towards the development of sustainable future. Different types of plant fibres are cultivated all over the world [2,3]. Jute is mainly produced in India and Bangladesh; tropical countries cultivate coir and sisal. United States is famous for commercial production of kenaf, whereas Europe produces flax and hemp. Some characteristics of these plant fibres like renewability, recyclability, biodegradability, low price, low density, and attractive mechanical properties make them a potential alternative to synthetic fibres. Plant fibre-reinforced composites are environmentally friendly and their use is slowly increasing in various areas, like transportation, building and construction industries, packaging, consumer products, etc. [4]. Plant fibres mainly comprise of cellulose, hemicellulose, lignin, waxes, ash, and water-soluble compounds. The chemistry and structure of the fibres determine their characteristics, functionalities, and processing efficiencies.

1.2 Plant fibres

Fibres are divided into two main categories, (1) natural fibres and (2) synthetic fibres. Natural fibres are subdivided based on their origins, like plant, animal, and mineral fibres. Plant fibres are often used as reinforcement in biocomposites. From biological science perspective plant fibres are mainly lignified secondary cell walls, called sclerenchyma cells, which give mechanical stability to the plant body. Some examples of these plant fibres include, cotton, jute, ramie, sisal, flax, hemp, etc. The classification of plant fibres is shown in Fig. 1.1.

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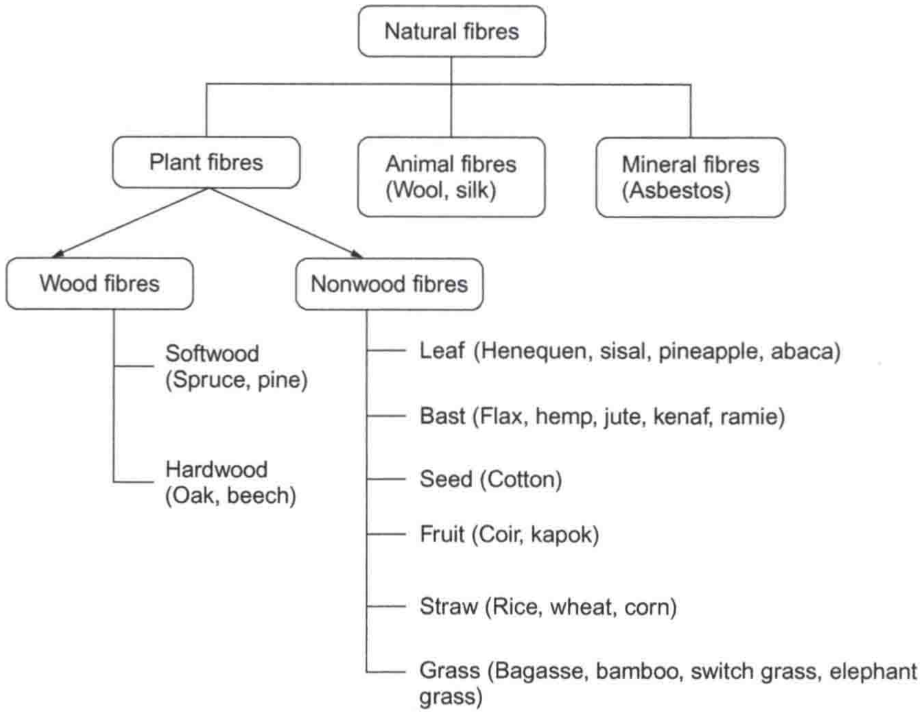

Fig. 1.1 Schematic representation of classification of natural fibres [2,3,5].

1.2.1 Sources of plant fibres

Plant fibres are classified based on their origin, i.e., the part of the plant from which they are derived (Fig. 1.1). Wood fibres are the main structural elements of wood, and are basically spindle-shaped cells of wood [6]. Wood fibres are extracted from wood by various mechanical and chemical pulping methods and are used as reinforcements in polymer composites. For composite applications wood flour is more attractive than individual wood fibres because of its low price and processing ease with conventional plastic processing methods. Wood fibres are of two types, softwood and hardwood. Bast fibres include flax, hemp, jute, kenaf, ramie, etc. These fibres are collected from inner bark (called phloem or bast) of the stems of the dicotyledonous plants [7]. Leaf fibres, which include, sisal, henequen, pineapple, abaca, etc., are obtained from leaves of monocotyledonous plants. Seed and fruit fibres are obtained from seeds and fruits of the plants, respectively. Straw fibres are actually stalks of the plants. Among all these plant fibres, flax, jute, ramie, kenaf, and cotton are commonly used as reinforcing materials in composites. According to 1997 report, 20 million metric ton of plant fibres were produced worldwide and cost of these fibres depend on the economy of the countries where they are produced [2,3]. Table 1.1 summarizes the production of some plant fibres and the places where these fibres are cultivated.