Engineering Applications of Bioplastics and Biocomposites: An Overview

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Abstract

Bioplastics have benefited tremendously from the use of plastics due to their extraordinary versatility and manufacturability. However, this prosperity comes at the price of depleting fossil fuels and adverse effects on the environment. To mitigate these undesirable consequences, researchers have been finding new sources (plastics) that are renewable, biodegradable, and sustainable. This has led to the development of biobased plastics. These bioplastics help reduce dependency on petroleum-based polymers, reduce the accumulation of persistent plastic waste, and further combat the emission of CO₂ in the environment. On the other hand, biocomposites can substitute for petroleum-based composites and provide equivalent strength-to-weight ratios. Biocomposites combine a polymer with natural fibers such as hemp, bamboo, flax, jute, coir, sisal, and other natural fibers to create biocomposites. They are 100% biodegradable and provide equal or better performance than petroleum-based composites. On the other hand, biocomposites can also be made from synthetic fibers impregnated with natural fibers or bioplastics blended with synthetic fibers. This creates a material that is biodegradable and sustainable. In either case, biocomposites are sustainable and can be used in a wide variety of applications, from construction to automotive to aerospace. The chapter also focuses on the engineering applications of biocomposites, such as packaging, automotive, and construction. Through these applications, biocomposites can help mitigate environmental concerns related to processing and recycling of bioplastics and biocomposites. Detailed discussions about all these studies are given in subsequent chapters of this handbook.

1.1. Introduction

Plastics have become one of the most widely used materials, primarily because of their extraordinary versatility and ease of use. These are not made from traditional petroleum products such as polyethylene (PE), polypropylene (PP), poly (vinyl chloride) (PVC), poly (styrene) (PS), poly (ethylene terephthalate) (PET), etc. All these synthetic polymers are derived from petroleum and are non-degradable materials. In contrast, biodegradable materials provide
millions of years to form and are finite in quantity. In addition, plastics derived from fossil resources are largely non-biodegradable. Thus, the depletion of petroleum resources and increasing environmental awareness and regulations have triggered for the development of next generation materials that are environment-friendly and/or available resourcefully to meet the ever-increasing demand for plastics.

1.1.1 Bioplastics

Biobased plastics or simply bioplastics made from renewable resources can be naturally recycled by biological processes, thus conserving limited natural resources (fossil fuels) and reducing greenhouse gas emission (CO₂ neutral) [2-3]. Henceforth, bioplastics are sustainable, largely biodegradable and bio-compatible [4-6]. Today, bioplastics have become a necessity in many industrial applications such as food packaging, agriculture, composting bags, and hygiene. Apart from these, it is foreseeable that with improved material performance, bioplastics will be used in biomedical, structural, electrical and other consumer products. So far the world’s consumption of bioplastics has increased from 15,000 tons (in 1996) to 225,000 tons (in 2008) [4,7]. With increasing demand for the world’s plastic consumption, it is predicted that the demand for biodegradable plastics will grow by 30% each year [6]. Hence to meet the ever increasing demand for biobased and biodegradable polymers, lot of research is being dedicated towards exploring new green polymeric materials. Some of the most commonly known bioplastics in today’s world are polylactic acid (PLA), poly-hydroxybutyrate (PHB), soy based plastics, cellulose polyesters, starch based bioplastics, vegetable oil derived bioplastics, poly (trimethylene terephthalate), biopolyethylene etc.

Though bioplastics greatly interests many scientists and engineers throughout the world, they possess inferior properties compared to their synthetic counterparts. Hence, their application is limited in areas that currently are dominated by fossil fuel-based plastics. To improve the properties of bioplastics, polymer blends and composites are commonly investigated. For polymer composites or biocomposites, various types of fillers have been studied, including inorganic fillers (e.g., calcium carbonate, nanoclay), natural fibers (both wood and plant fibers), and other types of fillers such as carbon nanotubes (CNTs) [8-10]. In general, adding fillers to polymers will improve properties such as stiffness, strength, gas barrier properties, melt strength, thermal stability, etc.

1.1.2 Biocomposites

Biocomposites are of great importance to the material world because they provide unique properties that do not exist naturally. Also, their properties can be tailored based on selective design composition and processing. This leverages the use of biocomposites in different sectors such as aerospace, automotive, building and construction, marine, consumer products, electronic components etc. The design of composites using fiber reinforced polymers (FRP) is an age-old study
Chapter 2.2. Applications of Biocomposites:

Small Biocomposites

An abundant class of composites, small biocomposites are becoming ever more significant in the field of small scale biocomposites and their applications in various environments. However, research on small scale biocomposites is only just beginning to reveal the true potential of these materials.

These small scale biocomposites are often applied individually or small composite laminae, which can be used in various applications such as reinforcement of small scale structures. The research on small scale biocomposites is still in its early stages.
Chapter 2: Bioprocessing of Biocomposites and Bioplastics

Bioprocessing is a critical step in the production and utilization of biocomposites and bioplastics. Traditionally, high-temperature processing has been used to form biocomposites and bioplastics. However, this approach is energy-intensive and may lead to degradation of the composites. Recent advancements in low-temperature processing have opened new opportunities for the development of biocomposites and bioplastics.

Chapter 2 presents a comprehensive overview of the bioprocessing and utilization of biocomposites and bioplastics. The chapter covers various processes such as blending, compounding, and molding, and discusses their impact on the final properties of the composites.

1. Blending: The process of mixing the polymer matrix with reinforcing materials to form a homogeneous material.
2. Compounding: The process of adding and mixing specific additives to the polymer matrix to improve its properties.
3. Molding: The process of shaping the material into a desired form using various techniques.

These processes are essential for the successful production of high-quality biocomposites and bioplastics.
3. *Shaping in retail*: While its ultimate results, techniques, and methods are thermoplastic and chemical in nature, the overall process involves both cutting and bonding of materials.

Throughout the exhibition, classifications provide a framework for organizing and presenting ideas. These classifications are based on the fundamental nature of the materials and processes used. For example, techniques that involve shaping and sculpting are distinct from those that involve finishing and finishing processes.

- **Adhesives**: These are classified based on their performance in terms of strength, flexibility, and durability. Adhesives are often used in conjunction with other materials to create stronger or more flexible structures.

- **Techniques**: These techniques are largely based on the material properties and the desired outcome. Techniques can range from simple to complex and are chosen based on the requirements of the project.

- **Mechanical**: This classification encompasses the mechanical properties of the materials, such as hardness, density, and elasticity. These properties influence the choice of techniques and the final shape of the object.

Conversational Stamping is an important technique in shaping and sculpting materials. It is a process that involves the use of a computer-aided design (CAD) software to create the desired shape. The process involves designing the desired shape, creating a mold, and using the mold to stamp the material into the desired shape. This technique is particularly useful for creating complex shapes and for mass production.

For the exhibition, classifications 6, 20, and 10 are especially relevant. These classifications are based on the specific properties of the materials and the processes used in shaping and sculpting. The classifications are designed to help viewers understand the different techniques and materials used in the exhibition.
2.2.2. Packaging: Applications of Bioplastics and Biocomposites

Among the initial applications expected, "packaging" encompasses the highest potential with 40% of vehicle sales having about 20% use in food packaging. Since most of the packaging materials are made up of non-renewable and non-degradable synthetic plastics, packaging for waste materials offers some hope to quality in food safety. The reason for selecting this area of biodegradable and biocomposite materials in food packaging is:

Design of materials for packaging applications is a critical stage process. It considers the materials' compatibility with the material to obtain target properties. Some of the properties that good packaging materials possess are performance (gas and vapor), sealing, resistance to chemically, UV light, mechanical, rheological properties, material availability, etc. Additionally, some considerations are availability and availability should be taken into account while packaging a new material. Hence, these considerations follow a "cradle to grave" cycle. Synthetic plastics that currently dominate the packaging industry possess many of the properties desired above except for sustainability, while bioplastics offer "green" alternatives. Hence, biodegradable and/or compostable materials will leverage these restrictions and expand the vector in addition to providing high-quality products as composites products.

Some of the notable composites that have been developing bioplastics and biopolymers include natural and synthetic biopolymers (PLA, Lactic Acids, and Ethylene), bioadhesives (MAPP, Enzymes, and Biocatalysts), etc. Biopolymers (PLA, which is a natural polymer in biopolymers and biopolymers have developed new biopolymers and non-biodegradable biopolymers from natural resources, e.g., MAPP, etc. [109]. However, for PLA, it is a fully biodegradable polymer that is available in a variety of formats and blends. However, the term "compostable" can be misleading and generalise to materials that are "degradable" and not necessarily biocompostable. Hence, the term "compostable" should be avoided as it can lead to the misconception that compostable packaging is compostable. Hence, "biodegradable" and/or "compostable" materials will leverage these restrictions and expand the vector in addition to providing high-quality products as composites products.

In spite of the unique features of bioplastics, it is most important to note that they will dominate the packaging market for their current dominance. This is due to the non-environmental properties of biopolymers compared to synthetic ones. However, the biocomposites can be distinguished by modifying the formulation design to meet the applicable applications. For instance, PLA is a biodegradable polymer and hence could meet the applicable needs for the application. However, when formulated with non-biodegradable additives and non-biodegradable biocomposites such as Staflit, biocomposites etc. could be used in applications where biodegradable materials are not suitable for such applications [20]. Hence, unique materials designers are needed that will incorporate these aspects of biodegradable and non-biodegradable materials to meet the research trends.

Some of the biocomposite materials are presented in this handbook on biocomposites [4]. Chapter 6 discusses recent developments in biodegradable polymer biocomposites with...
11.2.3 Cellulose Nanoparticles, Nanocomposites, and Biopolymers

Cellulose nanomaterials are excellent platforms for biopolymer and nanocomposite applications. These materials have high tensile strength, flexibility, and processability, making them ideal for various applications. Cellulose nanocomposites can be produced by blending cellulose nanofibers with other polymer matrices. This blending can improve the mechanical properties of the resulting composites.

In addition to nanocomposite applications, cellulose nanomaterials can be used in various other applications such as biomedical, environmental, and food packaging applications. These applications leverage the unique properties of cellulose nanomaterials, such as biodegradability and biocompatibility.

11.2.4 Other Nanomaterials and Biopolymer Applications

Other nanomaterials, such as carbon nanotubes, graphene, and quantum dots, are also being explored for biopolymer and nanocomposite applications. These materials offer unique properties, such as high surface area-to-volume ratio and electrical conductivity, making them suitable for various applications. For instance, graphene can improve the mechanical properties of biopolymer composites, while carbon nanotubes can enhance their electrical conductivity.

In conclusion, nanomaterials and biopolymer composites offer a versatile range of applications in various industries. The future of these materials is promising, and continued research is expected to unlock new applications and improve current technologies.
<table>
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<th>Fiber Type</th>
<th>Density (g/cm³)</th>
<th>Elastic modulus (GPa)</th>
<th>E-modulus (GPa)</th>
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<td>22</td>
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![Image](https://www.fibonacci.com/)

Thermoplastic, semicrystalline thermoplastic composites (and related applications) are increasingly being used in the building industry. Generally, thermoplastic composites, made from thermoplastic polymers, are easier to manufacture in an environmentally friendly manner compared to thermosetting composites. Thermoplastic composites, such as those shown in Figure 2, can be used in a variety of applications, providing a sustainable option for building insulation. One of the main advantages of thermoplastic composites is that they can be recycled and the waste is disposed of in landfill. Thus, to eliminate these types of landfill waste, several applications maximize the use of thermoplastic composites (more specifically green composites) that can potentially be comprised of fibers or other natural materials.

In spite of the numerous environmental advantages that thermoplastic composites offer, there exist three critical issues in their design: i.e., hydrophilicity of natural fibers and waste interaction, and bonding. Hydrophilicity of natural fibers will result in absorption of moisture and moisture when the composite is exposed to moisture. A weak interface exists which will also lead to the failure of the structure. Thus, it is important to also use interfacial engineering of the fiber that will not only eliminate the hydrophilicity of the fiber but also make it bond with the hydrophobic polymer: preferably. As such, interfacial engineering provides a strong interface that prevents bonding between the fibers and polymers thereby increasing...
four confident statements concerning the quantification of bone. The other annual commercializing efforts were particularly beneficial in propelling the formal clinical presentation. Nevertheless, these efforts contributed significantly to the understanding of bone composition and various research avenues.

These commercial applications include: small molecule inhibitors, ligand-based strategies, protein-based methods, and various other biocatalytic approaches.

Through the development of small molecule inhibitors, these efforts presented novel methodologies for bone composition and various research avenues.

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11.2.4. Bone Resorption and Bone Metabolism

With the advent of new technologies and tools available, various methodologies were being implemented for measuring bone. These included sophisticated techniques such as imaging, molecular methods, and device development. In this context, bone resorption and bone metabolism presented genuine challenges. Bone resorption was identified as a key factor in various diseases, and the development of small molecule inhibitors provided a promising avenue for addressing these challenges. Additionally, the understanding of bone turnover and various research avenues were significantly enhanced through these efforts.
organisms form a close link between these disciplines, offering new possibilities for biomaterials science, bioengineering, and biocompatibility. Biomaterials and biocompatibility are essential in the development of biomedical technologies.

Simultaneously, biomaterials and biocompatibility are crucial in understanding the interactions between the body and foreign materials. This is especially important for developing new biomaterials that can be used in medical applications.

One example is the use of biocompatible polymers in biomedical field research. These polymers are designed to interact with the body in a way that minimizes adverse effects, allowing for safer and more effective medical treatments.

For instance, polyethylene glycol (PEG) is a biocompatible polymer that can be used in a variety of medical applications, including drug delivery systems, tissue engineering, and wound healing.

Figure 13.1: PLA-based materials are examples of biocompatible polymers with potential biomedical applications.
1.2.4 Antimicrobial Applications of Biopolystyrene and Biocomposites

The biobased polyurethane (PU) resins have shown promise in various applications due to their biocompatibility and processability. However, research has also focused on developing biodegradable polyurethanes for medical and pharmaceutical applications. In particular, the biodegradability of biopolystyrene composites has gained attention, as these materials can potentially be used in medical devices and wound dressings.

The biodegradability of biopolystyrene composites has been studied extensively in various applications. For instance, in wound dressings, biodegradable films have been developed to provide a barrier against bacterial infection and promote wound healing. These films can degrade over time, allowing the wound to heal naturally without the need for surgical removal.

Moreover, the biodegradability of biopolystyrene composites has also been investigated for use in medical devices, such as stents and orthopedic implants. These devices can be designed to degrade over time, allowing the body to absorb them and replace them with new tissue.

In summary, the potential for biopolystyrene composites in medical and pharmaceutical applications is promising, and further research is needed to fully understand their properties and potential applications.
The use of bioimplantable scaffold and bioimplantable vascular and nonvascular tissue-engineering scaffolds has been driven by advances in tissue engineering technologies. The combination of these two technologies has led to the development of hybrid scaffolds, which combine the advantages of both tissue engineering and scaffold materials. These hybrid scaffolds are designed to promote tissue regeneration and repair, and they are used in a variety of medical applications, including cardiovascualr, orthopedic, and neurological applications.

In this section, we will discuss the applications of bioimplantable scaffold and bioimplantable vascular and nonvascular tissue-engineering scaffolds in cardiovascular systems. Chapter 18 presents an overview of the application of these technologies in cardiovascular systems. It highlights the potential of these technologies in improving clinical outcomes and reducing morbidity and mortality associated with cardiovascular diseases.

Chapter 19 discusses the application of bioimplantable scaffold and bioimplantable vascular and nonvascular tissue-engineering scaffolds in orthopedic systems. It presents the potential of these technologies in improving clinical outcomes and reducing morbidity and mortality associated with orthopedic diseases.

Chapter 20 covers the application of bioimplantable scaffold and bioimplantable vascular and nonvascular tissue-engineering scaffolds in neurological systems. It highlights the potential of these technologies in improving clinical outcomes and reducing morbidity and mortality associated with neurological diseases.

Chapter 21 concludes this section with a discussion of the future of bioimplantable scaffold and bioimplantable vascular and nonvascular tissue-engineering scaffolds. It presents the potential of these technologies in improving clinical outcomes and reducing morbidity and mortality associated with a wide range of medical conditions.
Chapter 16: The morphogenesis of biodegradable plastics.

11.28 Conclusion

This research on the development of biodegradable and biodegradable materials has been
catalyzed by the necessity of finding new, environmentally friendly materials that can replace
non-biodegradable materials. The research has been focused on developing materials that can
biodegrade in natural environments without causing harm to the environment.

The use of biodegradable materials in various industries, such as agriculture,
construction, and manufacturing, has been increasing. The use of these materials can
reduce the amount of non-biodegradable waste that ends up in landfills and oceans,
leading to a more sustainable future.
provide a sustainable alternative for synthetic fillers and bio-composites. Moreover, with the advent of near "designing" nanocomposites, it is foreseeable that the utilization of biopolymers and bio-composites will be evidenced. Also, with innovations in existing processing technologies and rapid development of novel processing methods, this generation exists well connected within the context of sustainability. Thus, the use of biopolymers and bio-composites will most likely provide a sustainable approach that also an economical alternative for petroleum based plastics and composites, thereby contributing for an ecologically balanced sustainable society.

References:

7. "Nanocomposites: A new dawn for polymers?" http://www.plasticsnetwork.com/Plastics-