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Biodegradable Polymers

***K. Sandhyarani, N.Madhusri, G.Lavanya**

Avanthi Institute of Engineering and Technology, Vizianagaram , Andhrapradesh, India.

*Corresponding author Email: drsandhyanaidu@gmail.com

Abstract: *The growing environmental concerns associated with conventional petroleum-based plastics, coupled with rising oil prices and waste-disposal challenges, have accelerated interest in biodegradable polymers. These materials, derived from either renewable natural resources or non-renewable petroleum feedstocks, offer a sustainable alternative to traditional plastics. Biodegradation occurs through enzymatic and chemical actions of living organisms, involving polymer fragmentation followed by microbial assimilation and mineralization. The biodegradability of polymers depends on their chemical structure, molecular architecture, and environmental conditions. Among biodegradable polymers, aliphatic polyesters—particularly polylactide (PLA)—have attracted significant attention due to their hydrolysable ester bonds and favorable mechanical properties. PLA, synthesized from lactic acid via polycondensation or ring-opening polymerization, exists in different optical forms that influence its physical behavior and applications. Biodegradable polymers can be processed using conventional plastic processing techniques and are increasingly utilized across diverse sectors, including medicine, packaging, agriculture, automotive, electronics, and construction. Their applications range from biomedical implants and controlled drug delivery systems to packaging films, agricultural mulch films, lightweight automotive components, electronic casings, and construction materials. Overall, biodegradable polymers represent a promising class of materials that address environmental sustainability while meeting functional and industrial performance requirements.*

1. INTRODUCTION

Biodegradable materials are used in packaging, agriculture, medicine and other areas. In recent years there has been an increase in interest in biodegradable polymers. Two classes of biodegradable polymers can be distinguished: synthetic or natural polymers. There are polymers produced from feed stocks derived either from petroleum resources (non renewable resources) or from biological resources (renewable resources). In general natural polymers offer fewer advantages than synthetic polymers.

The same durability properties which make plastics ideal for many applications such as in packaging, building materials and commodities, as well as in hygiene products, can lead to waste-disposal problems in the case of traditional petroleum-derived plastics, as these materials are not readily biodegradable and because of their resistance to microbial degradation, they accumulate in the environment. In addition in recent times oil prices have increased markedly. These facts have helped to stimulate interest in biodegradable polymers and in particular biodegradable biopolymers. Biodegradable plastics and polymers were first introduced in 1980s. There are many sources of biodegradable plastics, from synthetic to natural polymers. Natural polymers are available in large quantities from renewable sources, while synthetic polymers are produced from non renewable petroleum resources.

2. BIODEGRADATION

Biodegradation takes place through the action of enzymes and/or chemical deterioration associated with living organisms. This event occurs in two steps. The first one is the fragmentation of the polymers into lower molecular mass species by means of either abiotic reactions, i.e. oxidation, photodegradation or hydrolysis, or biotic reactions, i.e. degradations by microorganisms. This is followed by bioassimilation of the polymer fragments by microorganisms and their mineralisation. Biodegradability depends not only on the origin of the polymer but also on its chemical structure and the environmental degrading conditions.

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Most conventional polymers derived from petroleum resources are resistant to degradation. To facilitate their biodegradation, additives are added. One method to degrade polyolefins consists in the introduction of antioxidants into the polymer chains. Antioxidants will react under UV, inducing degradation by photo-oxidation. Nevertheless the biodegradability of such systems is still controversial. We prefer to consider them as oxo-degradable polymers

Polymers with hydrolysable backbones are susceptible to biodegradation under particular conditions. Polymers that have been developed with these properties include polyesters, polyamides, polyurethanes and polyureas, poly(amide-enamine)s, polyanhydrides

3. CLASSIFICATION

The aliphatic polyesters are almost the only high molecular weight biodegradable compounds and thus have been extensively investigated. Their hydrolysable ester bonds make them biodegradable. Aliphatic polyesters can be classified into two types according to the bonding of the constituent monomers. The first class consists of the polyhydroxyalkanoates.

Polylactide (PLA): PLA is usually obtained from polycondensation of D- or L-lactic acid or from ring opening polymerization of lactide, a cyclic dimer of lactic acid. Two optical forms exist: D-lactide and L-lactide. The natural isomer is L-lactide and the synthetic blend is DL-lactide

4. APPLICATIONS

Biodegradable polymers can be processed by most conventional plastics processing techniques, with some adjustments of processing conditions and modifications of machinery. Film extrusion, injection moulding, blow moulding, thermoforming are some of the processing techniques used. The three main sectors where biodegradable polymers have been introduced include medicine, packaging and agriculture. Biodegradable polymers applications include not only pharmacological devices, as matrices for enzyme immobilization and controlled-release devices but also therapeutic devices, as temporary prostheses, porous structure for tissue engineering.

Medicine and pharmacy: Biodegradable polymers used as biomaterials have been recently review to be used as biomaterials, biodegradable polymers should have three important properties: biocompatibility, bioabsorbility and mechanical resistance. Current applications of biodegradable polymers include surgical implants in vascular or orthopaedic surgery and plain membranes.

Packaging: In everyday life, packaging is another important area where biodegradable polymers are used. In order to reduce the volume of waste, biodegradable polymers are often used. Besides their biodegradability, biopolymers have other characteristics as air permeability, low temperature sealability. Biodegradable polymers used in packaging require different physical characteristics, depending on the product to be packaged and the store conditions.

Agriculture: For this application, the most important property of biodegradable polymers is in fact their biodegradability. Starch-based polymers are the most used biopolymers in this area. They meet the biodegradability criteria and have a sufficient life time to act.

Plastic films were first introduced for greenhouse coverings fumigation and mulching in the 1930s. Young plants are susceptible to frost and must be covered. The main actions of biodegradable cover films are to conserve the moisture, to increase soil temperature and to reduce weeds in order to improve the rate of growth in plants.

Biodegradable polymers can be used for the controlled release of agricultural chemicals. The active agent can either be dissolved, dispersed or encapsulated by the polymer matrix or coating, or is a part of the macromolecular backbone or pendent side chain. The agricultural chemicals concerned are pesticides and nutrients, fertilizer, pheromones to repel insects. The natural polymers used in controlled release systems are typically starch, cellulose, chitin, aliginic acid and lignin

Automotive: The automotive sector aims to prepare lighter cars by use of bioplastics and biocomposites. Natural fibers can replace glass fibers as reinforcement materials in plastic car parts

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Electronics: PLA and kenaf are used as composite in electronics applications. Compact disks based on PLA are also launched on the market by the Pioneer and Sanyo groups. Fujitsu Company has launched a computer case made of PLA

Construction: PLA fiber is used for the padding and the paving stones of carpet. Its inflammability, lower than that of the synthetic fibers, offers more security. Its antibacterial and antifungal properties avoid allergy problems . The fiber is also resistant to UV radiation

5. CONCLUSION

Biodegradable polymers have emerged as an effective and sustainable alternative to conventional petroleum-based plastics, addressing critical environmental issues such as plastic waste accumulation and resource depletion. Their ability to undergo degradation through natural biological processes makes them particularly suitable for applications where disposal and environmental impact are major concerns. Among the various biodegradable materials, aliphatic polyesters—especially polylactide (PLA)—stand out due to their favorable biodegradability, processability, and mechanical performance. The versatility of biodegradable polymers allows their use across a wide range of sectors, including medicine, packaging, agriculture, automotive, electronics, and construction. In biomedical applications, their biocompatibility and bioabsorbability enable their use in implants and drug delivery systems, while in packaging and agriculture they contribute significantly to waste reduction. Although challenges related to cost, durability, and performance optimization remain, ongoing research and technological advancements continue to enhance their properties and expand their applications. Overall, biodegradable polymers play a crucial role in promoting sustainable development and represent a key material solution for reducing environmental pollution and supporting a circular economy.

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