Biodegradable Polymers and Its Applications

A. Ashwin Kumar , Karthick. K, and K. P. Arumugam

Abstract—**In recent years, there has been a marked increase in interest in biodegradable materials for use in packaging, agriculture, medicine, and other areas in India. In particular, biodegradable polymer materials (known as biocomposites) are of interest. Polymers form the backbones of plastic materials, and are continually being employed in an expanding range of areas. As a result, many researchers are investing time into modifying traditional materials to make them more user-friendly, and into designing novel polymer composites out of naturally occurring materials. A number of biological materials may be incorporated into biodegradable polymer materials, with the mostcommon being starch and fiber extracted from various types of plants. The belief is that biodegradable polymer materials will reduce the need for synthetic polymer production (thus reducing pollution) at a low cost, thereby producing a positive effect both environmentally and economically. This paper is intended to provide a brief outline of work that is under way in the area of biodegradable polymer research and development, the scientific theory behind these materials, areas in which this research is being applied, and the major advantages of this biodegradable polymer materials in India.**

Index Terms—**Biopolymer, biodegradable, plastic, agricultural products, biomaterial, recycling, life cycle assessment, environmental impact, economic impact, compost.**

I. Introduction

Synthetic plastics are resistant to degradation, and consequently their disposal is fuelling an international drive for the development of biodegradable polymers. As the development of these materials continues, industry must find novel applications for them. Material usage and final mode of biodegradation are dependent on the composition and processing method employed. An integrated waste management system may be necessary in order to efficiently use, recycle, and dispose of biopolymer materials . Reduction in the consumption of sources, reuse of existing materials, and recycling of discarded materials must all be considered. Polymer materials are solid, non-metallic compounds of high molecular weights. They are comprised of repeating macromolecules, and have varying characteristics depending upon their composition. Each macromolecule that comprises a polymeric material is known as a mer unit. A single mer is called a monomer, while repeating mer units are known as polymers. A variety of materials (both renewable and non-renewable) are employed as feedstock sources for modern plastic materials. Plastics that are formed from non-renewable feedstocks are generally petroleum-based, and reinforced by glass or carbon. Renewable resource feedstocks include microbially-grown polymers and thoseextracted from starch. It is possible to reinforce such materials with natural fibers, from plants such as flax, jute, hemp, and other cellulose.

II. Biodegradability of Polymers

The American Society for Testing of Materials (ASTM) and the International Standards Organization (ISO) define degradable plastics as those which undergo a significant change in chemical structure under specific environmental conditions. These changes result in a loss of physical and mechanical properties, as measured by standard methods. Biodegradable plastics undergo degradation from the action of naturally occurring microorganisms such as bacteria, fungi, and algae. Plastics may also be designated as photodegradable, oxidatively degradable, hydrolytically degradable, or those which may be composted. Between October 1990 and June 1992, confusion as to the true definition of “biodegradable” led to lawsuits regarding misleading and deceitful environmental advertising . Thus, it became evident to the ASTM and ISO that common test methods and protocols for degradable plastics were needed. There are three primary classes of polymer materials which material scientists are currently focusing on. These polymer materials are usually referred to in the general class of plastics by consumers and industry. Their design is often that of a composite, where a polymer matrix (plastic material) forms a dominant phase around a filler material . The filler is present in order to increase mechanical properties, and decrease material costs.

III. Degradable Polyethylene

Symphony's material is the first example of 100% degradable polyethylene. The plastic, known as SPITEK, has the same mechanical properties and processing characteristics as regular polyethylene and so can be used in the same way to make products. However, it has a special ingredient - up to 3% of a degradable compostable plastic (DCP) additive made under license from its developers EPI. This additive acts as a catalyst for the degradation of the polyethylene, kick starting the process when conditions dictate.

IV. The Need for a Fully Degradable Plastic

The need for a fully degradable plastic is pressing. Millions of tonnes of plastic waste, including refuse sacks, carrier bags and packaging, are buried in landfill sites around

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the world each year. China generates about 16 million tonnes, India 4.5 million tonnes and the UK 1 million tonnes, of which more than 800,000 tonnes is waste polyethylene. Other disposal routes are possible for these materials, such as recycling and incineration, but as much of the waste plastic is mixed up with other materials in the domestic and industrial waste streams, separation is costly particularly for small items such as carrier bags.

Conventional polyethylene products can take longer than 100 years to degrade, taking up valuable landfill space and potentially preventing the breakdown of biodegradable materials contained, say, in a refuse sack Symphony claims that its new plastic could effectively increase the capacity of landfill sites by as much as 20 to 30% by breaking down in a short time and allowing other materials to degrade.

V. Degradation Properties

Polymer degradation is a change in the properties - tensile strength, colour, shape, etc - of a polymer or polymer based product under the influence of one or more environmental factors such as heat, light or chemicals. These changes are usually undesirable, such as changes during use, cracking and depolymerisation of products or, more rarely, desirable, as in biodegradation or deliberately lowering the molecular weight of a polymer for recycling. The changes in properties are often termed "ageing".In a finished product such a change is to be prevented or delayed. However degradation can be useful for recycling/reusing the polymer waste to prevent or reduce environmental pollution. Degradation can also be induced deliberately to assist structure determination.Polymeric molecules are very large (on the molecular scale), and their unique and useful properties are mainly a result of their size. Any loss in chain length lowers tensile strength and is a primary cause of premature cracking.

Surgeries are most common in India . Mostly metal plates are kept as the supporting material but now it is replaced by degradable polymer materials .The advantages of this are as follows

- Do not require a second surgery for removal .
- Avoid stress shielding .
- Offer tremendous potential as the basis for controlled drug delivery .
- As the above figure explains the graph between mechanical strength and time.

VI. Methods of Biodegradation

Just as important as the way in which a material is formed is the way in which it is degraded. A general statement regarding the breakdown of polymer materials is that it may occur by microbial action, photodegradation, or chemical degradation. All three methods are classified under biodegradation, as the end products are stable and found in nature.Many biopolymers are designed to be discarded in landfills, composts, or soil. The materials will be broken down, provided that the required microorganisms are present. Normal soil bacteria and water are generally all that is required, adding to the appeal of microbially reduced plastics .

Polymers which are based on naturally grown materials (such as starch or flax fiber) are susceptible to degradation by microorganisms. The material may or may not decompose more rapidly under aerobic conditions, depending on the formulation used, and the microorganisms required.

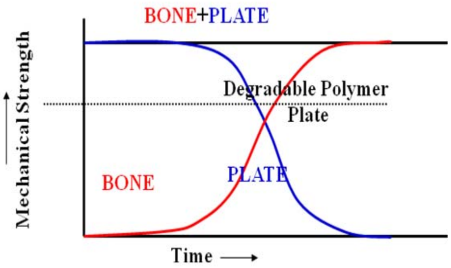

Fig. 1. A Graph Between Mechanical Strength And Time

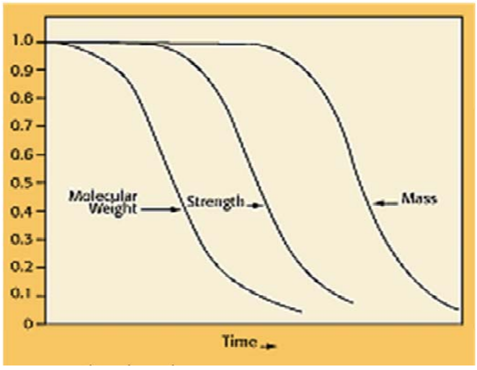

Fig. 2. Molecular weight,strength , mass vs time .

In the case of materials where starch is used as an additive to a conventional plastic matrix, the polymer in contact with the soil and/or water is attacked by the microbes. The microbes digest the starch, leaving behind a porous, spongelike structure with a high interfacial area, and low structural strength. When the starch component has been depleted, the polymer matrix begins to be degraded by an enzymatic attack. Each reaction results in the scission of a molecule, slowly reducing the weight of the matrix until the entire material has been digested .

Another approach to microbial degradation of biopolymers involves growing microorganisms for the specific purpose of digesting polymer materials. This is a more intensive process that ultimately costs more, and circumvents the use of renewable resources as biopolymer feedstocks. The microorganisms under consideration are designed to target and breakdown petroleum based plastics . Although this method reduces the volume of waste, it does not aid in the preservation of non-renewable resources. Photodegradable polymers undergo degradation from the action of sunlight . In many cases, polymers are attacked photochemically, and broken down to small pieces. Furthermmicrobial degradation must then occur for true biodegradation to be achieved. Polyolefins (a type of petroleum-based conventional plastic) are the polymers found to be most susceptible to photodegradation. Proposed approaches for further developing photodegradable biopolymers includes incorporating additives that accelerate photochemical reactions (e.g. benzophenone), modifying the composition of the polymers to include more UV absorbing groups (e.g. carbonyl), and synthesizing new polymers with light sensitive groups . An application for biopolymers which experience both microbial and photodegradation is in the use of disposable mulches and crop frost covers. Some biodegradable polymer materials experience a rapid dissolution when exposed to particular (chemically based) aqueous solutions. As mentioned earlier, Environmental Polymer's product Depart is soluble in hot water. Once the polymer dissolves, the remaining solution consists of polyvinyl alcohol and glycerol. Similar to many photodegradable plastics, full biodegradation of the aqueous solution occurs later, through microbial digestion. The appropriate microorganisms are conveniently found in wastewater treatment plants . Procter & Gamble has developed a product similar to Depart, named Nodax PBHB. Nodax is alkaline digestible, meaning that exposure to a solution with a high Ph causes a rapid structural breakdown of the material . Biopolymer materials which disintegrate upon exposure to aqueoussolutions are desirable for the disposal and transport of biohazards and medical wastes. Industrial "washing machines" are designed to dissolve and wash away the aqueous solutions for further microbial digestion.

VII. Applications for Biodegradable Polymers

Research and development is only a portion of the work that is done in order to introduce them use of biodegradable polymer materials. The design of such materials usually begins with a conceptual application. It may be expected to replace an existing material, or to complement one. Sectors where applications for biopolymers have introduced include (but are not limited to) medicine, packaging, agriculture, and the automotive industry. Many materials that have been developed and commercialized are applied in more than one of these categories. Biopolymers that may be employed in packaging continue to receive more attention than those designated for any other application. All levels of government, particularly in China and Germany , are endorsing the widespread application of biodegradable packaging materials in order to reduce the volume of inert materials currently being disposed of in landfills, occupying scarce available space. It is estimated that 41% of plastics are used in packaging, and that almost half of that volume is used to package food products. The renewable and biodegradable characteristics of biopolymers are what render them appealing for innovative uses in packaging. The end use of such products varies widely. The starch material is treated by an acetylation process, chemical treatments, and post-extrusion steaming. Mechanical properties of the material are adequate, and true biodegradability is achieved. The biopolymer materials suited for packaging are often used in agricultural products. Ecoflex, in particular, sees use in both areas. Young plants which are particularly susceptible to frost may be covered with a thin Ecoflex film. At the end of the growing season, the film can be worked back into the soil, where it will be broken down by the appropriate microorganisms. concluded that the use of a clear plastic mulch cover immediately following seeding increases the yield of spring wheat if used for less than 40 days. Therefore, plastic films that begin to degrade in average soil conditions after

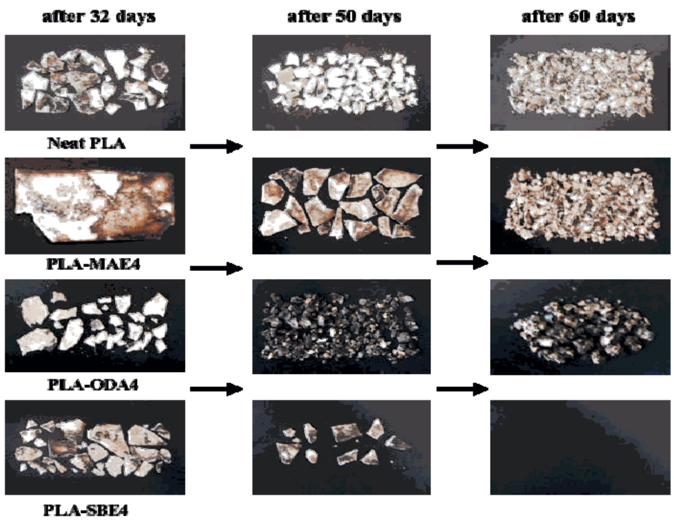

Fig. 3. Shows The Materials And The Degradation Period

the soil, and breakdown as the plant begins to grow. Fertilizer and chemical storage bags which are biodegradable are also applications that material scientists have examined. From an agricultural standpoint, biopolymers which are compostable are important, as they may supplement the current nutrient cycle in the soils where the remnants are added. The medical world is constantly changing, and consequently the materials employed by it also see recurrent adjustments. The biopolymers used in medical applications must be compatible with the tissue they are found in, and may or may not be expected to break down after a given time period. reported that researchers working in tissue engineering are attempting to develop organs from polymeric materials, which are fit for transplantation into humans. The plastics would require injections with growth factors in order to encourage cell and blood vessel growth in the new organ. Work completed in this area includes the development of biopolymers with adhesion sites that act as cell hosts in giving shapes that mimic different organs.

VIII. Environmental Impacts of Biopolymers

Engineers are attempting to integrate environmental considerations directly into material selection processes, in order to respond to an increased awareness of the need to protect the environment . The use of renewable resources in the production of polymer materials achieves this in two ways. First of all, the feedstocks being employed can be replaced, either through natural cycles or through intentional intervention by humans. The second environmental advantage of using renewable feedstocks for biopolymer development is the biodegradable nature of the end products, thereby preventing potential pollution from the disposal of the equivalent volume of conventional plastics. At the end of their useful period, biopolymer materials are generally sent to landfills or composted. Recycling of plastic materials is encouraged and well advertised, but attempts at expanding this effort have been less than effective. In the United States, currently less than 10% of plastic products are recycled at the end of their useful life . Recycling must be recognized as a disposal technique, not a final goal for material development. A complacent attitude regarding recycling processes ignores the fact that advanced infrastructure is needed to properly house recycling. As discovered, in underdeveloped countries plastics are almost completely recycled, as the return on investment is positive in their economic situation. This appears to be positive at the onset, but the open systems by which the plastics are recycled allow the emission of toxic gases at crucial levels.

IX. Conclusions

There are a seemingly limitless number of areas where biodegradable polymer materials may find use. The sectors of agriculture, automotives, medicine, and packaging all require environmentally friendly polymers. Because the level of biodegradation may be tailored to specific needs, each industry is able to create its own ideal material. The various modes of biodegradation are also a key advantage of such materials, because disposal methods may be tailored to industry specifications.

Environmental responsibility is constantly increasing in importance to both consumers and industry. For those who produce biodegradable plastic materials, this is a key advantage. Biopolymers limit carbon dioxide emissions during creation, and degrade to organic matter after disposal. Although synthetic plastics are a more economically feasible choice than biodegradable ones, an increased availability of biodegradable plastics will allow many consumers to choose them on the basis of their environmentally responsible disposal. The processes which hold the most promise for further development of biopolymer materials are those which employ renewable resource feedstocks. Biodegradable plastics containing starch and/or cellulose fibres appear to be the most likely to experience continual growth in usage. Microbially grown plastics are scientifically sound, and a novel idea, but the infrastructure needed to commercially expand their use is still costly, and inconvenient to develop. Time is of the essence for biodegradable polymer development, as society's current views on environmental responsibility make this an ideal time for further growth of biopolymers.

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