Review Article

A Review of Biodegradation of Plastics Waste

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ABSTRACT
A plastic can be defined as a wide range of synthetic or semi-synthetic organic solids used in the manufacturing of products from Industries. These are typically polymers of high molecular mass, and may contain other substances to improve performance and/or reduce production costs. Monomers of plastic are either natural or synthetic organic compounds. With the excessive use of plastics and increasing pressure being placed on available capacities for plastic waste disposal, the need for biodegradable plastics and biodegradation of plastic wastes has lead to its increased importance in the past few years. Lack of degradability and the closing of landfill sites as well as growing water and land pollution problems have led to concern about plastics. Awareness of the waste problem and its impact on the environment has awakened new interest in the area of degradable polymers. The interest in environmental issues is growing and there are increasing demands to develop material which do not burden the environment are being carried out .The use of micro-organisms in the environment to metabolize the molecular structure of plastic films to produce an inert humus-like material that is less harmful to the environment, moreover understanding their interaction and the biochemical changes they undergo are highly important. In addition, the use of bio-active compounds compounded with swelling agents ensures that when it is combined with heat and moisture, they expand the plastics molecular structure and allow the bio-active compounds to metabolize and neutralize the plastic.
This review looks at the technological advancement made in the development of more easily biodegradable plastics and the biodegradation of conventional plastics by microorganisms. Additives, such as pro-oxidants and starch, are applied in synthetic materials to modify and make plastics biodegradable. Reviewing published and ongoing studies on plastic biodegradation, this paper attempts to make conclusions on potentially viable methods to reduce impacts of plastic waste on the environment.

Keywords: thermoplastics, additive, thermoset plastics, biodegradation.

INTRODUCTION
The need for attention and awareness towards plastic degradation is at rise due to the ill effects caused by plastics in the recent years to the environment. For decades plastic bags and materials have been used for solid waste collection and disposal. They have proved to be a convenient way to contain waste and odours, given adequate storage and collection frequency. However, plastic bags and materials can be a disaster for composting systems incapable of decomposing. Plastics are long chain man-made synthetic polymeric molecules and are widely used, economical materials which are characterized by excellent all-round properties. They are easy to mold and manufacture. Generally plastics are very stable and not readily degraded. As a result, in today's world environmental pollution from synthetic plastics have been recognized as a large problem[1]. Biodegradable plastics are also of great interest to researchers. Biodegradable plastics are used in many fields like medicine, agriculture, building materials, food packaging industry and toys[2,6,7,8]. In case of biomedical implants and devices, biodegradable plastics are used as implants and can be designed according to the need[2]. There are also plastics which are commercially produced containing additives[6,7].

Types of Plastics
Thermoplastics and thermoset plastics are the two types of plastics. There are two main processes which are involved in the manufacture of these synthetic polymers by which they differ. The first method involves breaking of the double bond in the original olefin by additional polymerization to form new carbon-carbon bonds, the carbon-chain polymers. The second method is the elimination of water between a carboxylic acid

and an alcohol or amine to form polyester or polyamide. By this general reaction polyurethane is also manufactured[1]. Thermoplastics are produced by the breaking of the double bond. They can be hardened or softened by repeated heating and cooling process. Thermoplastics are considered as non-biodegradable plastics. The second type, thermoset plastics are synthesized using the second method. By heating after melting these plastics are solidified. Thermoset plastics are a highly cross-linked structure whereas thermoplastics are linear[1]. There are many types of biodegradable plastics which are derived from petroleum resources polymers with additives, hydrolysable backbones, aliphatic polyesters, polyglycolide, polylactide, polycaprolactone, polycarbonate. Polyurethanes and synthetic polymers with carbon backbone vinyl polymers. Biodegradable polymers which are derived from renewable resources are natural polymers or agro-polymers, proteins from animal sources, vegetable sources, polysaccharides from marine sources, vegetable sources. Bacterial polymers include semi synthetic and microbial polymers, microbial polyesters. There are certain blends of biodegradable polymers like starch based blends where starch is blended with many other plastics like PLA, PCL, PBS, and PHB [2]. There are alternatives to soft PVC toys. Biobased polymers from renewable sources and petroleum based plastics can be an alternative[8].

Application of plastics

These are the major applications of different types of plastics in various commercial products [1].

Table 1:

Types of plastics	Applications of plastics
Low density polyethylene (LDPE), linear low density polyethylene (LLDPE), polyvinylchloride (PVC)	Films and packaging
Polyethylene terephthalate (PET), PVC, high density polyethylene (HDPE)	Bottles, tubes, pipes, insulation molding
Polystyrene (PS), polypropylene (PP), PVC	Tanks, jugs, containers
LDPE, LLDPE	Bags
Polyurethane (PUR)	Coating, insulation, paints, packing

Biodegradation of plastics

Biodegradation is the chemical dissolution of materials by bacteria or by other biological means. Recently biodegradable plastics are of great interest. Biodegradation takes place by the action of enzymes, chemical degradation with living organisms. This takes place in two steps. The first step is the fragmentation of the polymers into lower molecular mass species by means of abiotic reactions, like oxidation, photodegradation or hydrolysis, or biotic reactions, like degradations by microorganisms. This step is followed by the bioassimilation of polymer fragments by the microorganisms and their mineralisation. Biodegradability depends not only on the origin of the polymer, also on its chemical structure and the environmental degrading conditions. The factors, on which the mechanical nature of biodegradable materials depends on, are their chemical composition, production, storage and processing characteristics, their ageing and the application conditions[2]. Degradable plastic is the one in which the degradation results from the action of naturally occurring microorganisms such as bacteria, fungi, and algae. Biodegradable plastics must biodegrade in specific environments such as soil, compost, or marine environments[7]. The biodegradable bags are made of polymers that degrade when exposed to sunlight, water or air[7].

Standard testing methods

1. Visual observations

The evaluation of visible changes in plastics can be performed in almost all tests. Effects used to describe degradation include roughening of the surface, formation of holes or cracks, de-fragmentation, changes in color, or formation of bio-films on the surface. These changes do not prove the presence of a biodegradation process in terms of metabolism, but the parameter of visual changes can be used as a first indication of any microbial attack. To obtain information about the degradation mechanism, more sophisticated observations can be made using either scanning electron microscopy (SEM) or atomic force microscopy (AFM) (Ikada, 1999). After an initial degradation, crystalline spherolites appear on the surface; that can be explained by a preferential degradation of the amorphous polymer fraction, etching the slower-degrading crystalline parts out of the material. In another investigation, (Kikkawa et al., 2002) used AFM micrographs of enzymatically degraded PHB films to investigate the mechanism of surface erosion. A number of other techniques can also be used to assess the biodegradability of polymeric material. These include; Fourier transform infrared spectroscopy (FTIR), differential scanning colorimetry (DSC), nuclear magnetic resonance spectroscopy (NMR), X-ray photoelectron spectroscopy (XPS), X-ray Diffraction (XRD), contact angle measurements and water uptake. Use of these techniques is generally beyond the scope of this review, although some are mentioned in the text.

2. Weight loss measurements

The mass loss of test specimens such as films or test bars is widely applied in degradation tests (especially in field- and simulation tests), although again no direct proof of biodegradation is obtained. Problems can arise with correct cleaning of the specimen, or if the material disintegrates excessively. In the latter case, the samples can be placed into small nets to facilitate recovery; this method is used in the full-scale composting procedure of DIN V 54900. A sieving analysis of the matrix surrounding the plastic samples allows a better quantitative determination of the disintegration characteristics. For finely distributed polymer samples (e.g., powders), the decrease in residual polymer can be determined by an adequate separation.

Mechanism of plastic biodegradation

It has been tested that plastic products that are manufactured with atleast 1% load by weight of the MBP will be fully biodegradable once they are placed in conditions wherein they are in constant contact with other biodegrading materials. The example for this is the biofilm formation[3]. There are enzymes, microorganisms used in the degradation of polymers[4,5,9].

i. Polyethylene and polypropylene

Polymers are applied in almost every field in day –to –day life from basic needs to sophisticated articles. This leads to enormous production and accumulation in the environment.

Polymer biodegradation involves the following steps

1. Attachment of the microorganism to the surface of the polymer.
2. Growth of microorganism by utilizing the polymer as the carbon source
3. Primary degradation of polymer
4. Ultimate degradation

There are certain methods to characterize the biodegradability of polymers. The polymers with high molecular weight are first degraded into oligomers of which some might be water soluble and then further broken down into organic intermediates like acids and alcohols. Some of the strategies involved are accumulation of biomass, oxygen uptake rate and surface changes[4].

ii. Polyurethane

Biodegradable polyurethane used in the medical field is synthesized from polycaprolactonediols. Polyurethanes of various length polyester subunits were made. Enzyme axion and two species of fungi were used to degrade polyurethane. Polyester polyurethane used in medical field is degraded by proteolytic enzyme like papin and urease. The degradation of polyurethane by cholesterol esterase was shown by treating the polyurethane with human neutrophil elastase and porcine pancreatic elastase. The results were that porcine pancreatic elastase reduced the polyurethane 10 times than human neutrophil elastase. There are also fungal and bacterial degradation of polyurethanes[5]. The enzyme degradation method of polyurethane can be done by isolating an enzyme polyurethane esterase (PUR esterase). This enzyme is isolated from the strain Comamonas acidovorans TB-35. This organism uses polyurethane as a sole carbon source9.

Bioplastics

Bioplastics are plastics which are biobased or biodegradable. The term 'oxo-biodegradable' is used by the producers of pro-oxidant additives. The oxo-biodegradable additives are typically incorporated into conventional plastics such as polyethylene, polystyrene, polypropylene, polyvinylchloride, polyethylene terephtalate. These additives are based on chemical catalysts, which contain transition metals such as cobalt, manganese, iron, etc., which cause fragmentation as a result of a chemical oxidation of the plastics polymer chains triggered by UV irradiation or heat exposure. The resulting fragments are claimed to eventually undergo biodegradation. There are also stabilizers added to limit the unwanted fragmentation of the polymer[6].

CONCLUSION

Thus there are biological methods employed to produce and degrade the polymers. The blended plastics are also a very good option to overcome the hazard of pollution. There are also other options like recycling of plastics. Recycling should be done in way that it will reduce pollution and to conserve energy.This review has covered the major concerns about the natural and synthetic polymers, their types, uses and degradability. It has looked at the disposal methods and the standards used in assessing polymer degradation. Another area examined has been the developments in the biodegradation of some of the newer polymers, either alone or in blended films.

There are a large number of tests which are used to determine the extent of degradation of polymers either alone or in blended forms. Many are respirometric, determining the amount of carbon dioxide released on exposure to fungi, bacteria, activated sludge (aerobically or anaerobically), compost or soil. Some tests use loss of weight or change in physical properties such as tensile strength and comparison of spectroscopic (FTIR, DSC, NMR, SEM, AFM, XRD) data. It is important to have comparable international standard methods of determining the extent of biodegradation. Unfortunately, the current standards have not, so far, been equated to each other and tend to be used in the countries where they originated [e.g. ASTM (USA), DIN (Germany), JIS (Japan), ISO (international standards), CEN (Europe)].
Many, which are otherwise harmonious, differ in the fine details of the testing. There is an urgent need to standardize all details so that researchers may know that they have all worked to the same parameters. It is clear that most recalcitrant polymers can be degraded to some extent in the appropriate environment at the right concentration. By judicious blending their persistence may be minimised environmentally. Screening of organisms which degrade polymers, or produce enzymes or enzyme systems that degrade polymers, may prove as environmentally profitable in the 21st century, as the screening program for antibiotics in the 1950 s and 1960 s. A screening program for such organisms and enzymes is required but will require more universally uniform standards for assessment of their degradative ability.

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