DEGRADATION OF PLASTICS FOR CLEAN ENVIRONMENT

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Abstract: *Plastic is a kind of material that is commonly known and used in everyday life. Plastics are defined as the polymers (solid materials) which on heating become mobile and can be cast into molds. Plastic wastes accumulating in the environment are posing an ever increasing ecological threat. Degradation of plastic is a great challenge as the materials are increasingly used. These solid waste related problems pose threat to our bio diversities. This growing concern has raised and promoted research activity worldwide to either modify current products to promote degradability or to develop new alternatives that are degradable. Plastics that are biodegradable can be considered environment friendly, they have an increasing range of potential application and lot of demand in market as it is safe for the environment. This paper highlights the various degradation processes and mechanism by which plastics can be degraded in the environment.*

Keywords: *Plastic, polymers, biodegradable, Degradation, molds*

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INTRODUCTION

The word 'plastic' is derived from the Greek word "plastikos", that means 'able to be molded into various shapes and sizes' [1]. Plastics are man-made long chain polymeric units [2]. The plastics are made from inorganic and organic raw materials, can be moulded into any desired shape and sizes. The basic materials are extracted from oil, coal and natural gas used for making plastics [3]. Plastic is the mother industry to hundreds of components and products that are manufactured and used in our daily life. Approximately 30% of plastics are used worldwide for packaging applications and the most widely used plastics used for packaging are polyethylene (LDPE, MDPE, HDPE, LLDPE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), polyurethane (PUR), polybutylene terephthalate (PBT), nylons. Plastic is a kind of organic polymer, which has molecules containing long carbon chains as their backbones with repeating units. The structure of these repeating units and types of atoms play the main role in determining the characteristics of the plastic. These long carbon chains are well packed together by entanglements and Van der Waals forces between large molecules, and form a strong, usually ductile solid material. Also, additives are usually added when manufacturing of commercial plastics is carried on, in order to improve the strength, durability or grant the plastic specific characteristics So plastics has become an indispensable part of the twenty-first century world. Plastics are resistant to microbial attack, because their short time of presence in nature evolution could not design new enzyme structures capable of degrading synthetic polymers[4]. Nowadays, a wide variety of petroleum-based synthetic polymers are produced worldwide to the extent of approximately 140 million tons per year and remarkable amounts of these polymers are introduced in the ecosystem as industrial waste products [5]. The dramatic increase in production and lack of biodegradability of commercial polymers, has focused public attention on a potentially huge environmental accumulation and pollution problem that could persist for centuries[6]. Plastic waste is disposed off through the process such as landfilling, incineration and recycling. Improperly disposed plastic play significant role in potentially harming life by causing environmental pollution.

TYPES OF PLASTICS

There are two types of plastics: thermoplastics and thermosetting polymers. Thermoplastics are plastics that do not undergo chemical change in their composition when heated and can be molded again and again. The molecules of thermoplastics are packed together by entanglements and Van der Waals forces. When a thermoplastic is heated up, it loses its entanglements and its molecules get farther away from each other, which causes the plastic changing from solid to liquid without breaking the bonds within the molecules. Thermosets are assumed to have infinite molecular weight. These chains are made of many repeating molecular units, known as repeating units, derived from monomers; each polymer chain will have several thousand repeating units. Thermosets can melt and can be molded into various shapes. After they are solidified, they remain solid. In the thermosetting process, a chemical reaction occurs which is irreversible. Vulcanization of rubber is a thermosetting process. The polyisoprene is a tacky, slightly runny material, before heating with sulfur, but after vulcanization the product is rigid and non-tacky. The molecules of thermosetting plastic are packed together not only by entanglements and Van der Waals forces, but also by the cross-links between molecules. When a thermosetting plastic is heated up, the cross-linking bonds between molecules break apart and the plastic turns into another substance when it melts, usually by decomposing [7]. Plastics can also be classified depending on various physical properties, such as density, high tensile strength, and resistance to various chemical products.

TOXICITY OF PLASTICS

Pure plastics generally have low toxicity due to their insolubility in water and relative chemical inertness. Some plastic products can be toxic due to the presence of some additives in them. For example, plasticizers like adipates and phthalates are often added to brittle plastics. Traces of these compounds can leach out of the product. The compounds leaching from polystyrene food containers have been proposed to interfere with hormone functions and are suspected human carcinogens. The finished plastic is non-toxic, the monomers that is used in the manufacture of the parent polymers may be toxic. But in some cases, small amounts of these chemicals can remain trapped in the product unless a suitable processing is being employed.

SYNTHETIC AND NATURAL PLASTICS

Synthetic Plastics are man-made and non-biodegradable whereas natural plastics are the products from renewable sources that totally biodegrade in their natural form and are components of plants, animals and algae. Natural plastics are biodegradable. Many bacteria and archaea synthesize biodegradable plastics which are a group of biopolymers.

PHA (Polyhydroxyalkanoates): ALTERNATIVE TO PETROCHEMICAL PLASTICS

PHA are a good alternative to petrochemical plastics among the various biodegradable polymers because they are biodegradable, eco-friendly and bio-compatible. Due to limiting natural resources, non petroleum based biological polyesters are considered as one of the most important next-generation polymers in the future. Polyhydroxyalkanoates (PHA) are the biodegradable polyesters that are produced by bacteria in order to overcome the environmental stress. A large number of bacteria remains in contaminated environment which can accumulate PHA as their energy reserves. The properties of PHA are also similar to those of polyethylene (PE) and polypropylene (PP). Classification of PHA can be done into different types according to the number of repeating units in the polymers. Short-chain-length PHA (scl-PHA) is the polymer that contain monomers of C3 to C5 hydroxyl fatty acids e.g. polyhydroxybutyrate (PHB) and hydroxyvalerate (PHV). Similarly, the polymers composed of C6 to C16 hydroxyl fatty acids or aliphatic carbon sources are termed as medium- chain -length PHA (mcl-PHA).

MICROORGANISM PRODUCING PHA

Many micro-organisms accumulate PHA as intracellular energy and storage of carbon inclusions when the carbon is in excess to the other nutrients such as nitrogen, sulfur, phosphorus and oxygen. PHA is produced by almost 250 organisms to be known, but only a few species can produce PHA at a high concentration e.g. Alcaligenes latus, Pseudomonas oleovorans, Cupriavidus necator .

DEGRADATION OF PLASTICS

Degradation of plastic is a great challenge as the materials are increasingly used. A very general estimate of worldwide plastic waste generation is annually about 57 million tons [8]. These solid waste related problems pose threat to ecosystems. The characteristics of polymer such as mobility, crystallinity, molecular weight, functional groups and substituents present in its structure, and plasticizers or additives when added to the polymer all play a significant role in its degradation [9,10]. Processes that induce changes in polymer properties due to physical,chemical or biological reactions resulting in subsequent chemical transformations are categorized as polymer degradation. The polymer is first converted to its monomers during degradation, after which these monomers are mineralized. Most polymers are too large that they can pass through cellular membranes, so for this they must first be depolymerized to smaller monomers before they can be absorbed and biodegraded within the microbial cells. The initial breaking down of polymers can result from a variety of physical and biological forces [11]. Any of the physical forces, such as heating, cooling, freezing, thawing, wetting or drying, can cause damage to the mechanical property such as the cracking of polymers [12].

Degradation are reflected as changes in properties of material (mechanical, optical or electrical characteristics), in cracking, erosion, discoloration, phase separation and delamination. The degradation of polymers has raised and promoted research activity world wide to either modify current products to promote degradability or to develop new alternatives that are degradable by any or all of the following mechanisms: Biodegradation, Photodegradation, Thermaldegradation, Oxo-biodegradation and Chemical degradation

Bio-degradation

Biodegradation is the process by which organic substances are broken down by living organisms. This term is often used in relation to ecology, waste management, bioremediation and to the growth conditions in the soil. Plastics are potential substrates for heterotrophic microorganisms . Biodegradation is governed by different factors that include characteristics of polymer, type of organism, and nature of pretreatment. Biodegradable polymers are designed to degrade upon disposal by the action of living organisms. Biodegradable polymers generally decompose in various medium in our environment. The depolymerisation results due to various physical biological forces. The physical forces such as temperature, moisture, pressure etc, deal with causing mechanical damage to the polymer. The microbial biodegradation is widely accepted and is still underway for its enhanced efficiency. Recently several microorganisms have been reported by various Research groups, to produce degrading enzymes. Microbial degradation of plastics is caused by enzymatic activities that lead to a chain cleavage of the polymer into monomers. The microbial species are associated with the degrading materials. Microbial degradation of plastics is caused by certain enzymatic activities that lead to a chain cleavage of the polymer into oligomers and monomers. These water soluble enzymatically cleaved products are further absorbed by the microbial cells where they are metabolized. Aerobic metabolism results in carbon dioxide and water, and anaerobic metabolism results in the production of carbon dioxide, water and methane and are called end products, respectively[10]. The degradation leads to breaking down of polymers to monomers creating an ease of accumulation by the microbial cells for further degradation.

Photodegradation

Sensitivity of polymers to photodegradation is related to the ability to absorb the harmful part of the tropospheric solar radiation. And this includes the UV-B terrestrial radiation (~ 295–315 nm) and UV-A radiation (~ 315–400 nm) responsible for the direct photodegradation (photolysis, initiated photooxidation). Visible part of sunlight (400–760 nm) accelerates polymeric degradation by heating. Infrared radiation (760–2500 nm) accelerates thermal oxidation [13]. The absorbance of high-energy radiation in the ultraviolet portion of the spectrum by most plastics, results in activation of their electrons to higher reactivity and that causes oxidation, cleavage, and finally process of degradation.

Thermal degradation

Thermal degradation of polymers is 'molecular deterioration as a result of overheating'. The components of the long chain backbone of the polymer can begin to separate (molecular scission) at high temperatures and react with one another to change the properties of the polymer. Various chemical reactions involved in thermal degradation lead to physical and optical property changes relative to the initially specified properties. Thermal degradation of plastics generally involve changes to the molecular weight (and molecular weight distribution) of the polymer and typical property changes include; reduced ductility and embrittlement, chalking, color change, and general reduction in most other desirable physical properties[14].

Oxo-biodegradation

Oxo-biodegradation process uses two methods : photodegradation (UV) and oxidation. The UV degradation process uses UV light to degrade the end product. The oxidation process makes use of time and heat to break down the plastic. Both the processes reduce the molecular weight of the plastic and allow it to biodegrade

The degradation of most synthetic plastics in nature is a very slow process that involves environmental factors, which follows the action of wild microorganisms [15,16]. The oxidation or hydrolysis by enzyme to create functional groups that improves the hydrophylicity of polymer is the the primary mechanism for the biodegradation of high molecular weight polymer. Consequently, the main chain of polymer is degraded resulting in polymer of low molecular weight and having feeble mechanical properties, which makes it more accessible for further microbial assimilation [16,17]. Poly(vinyl alcohol), poly(lactic acid), polycaprolactone, and polyamides are some examples of synthetic polymers along with oligomeric structures that biodegrade. The rate of degradation is affected by several physical properties such as crystallinity and orientation and morphological properties such as surface area [18].

Biodegradation by adding Additives (ECM's technology)

ECM's technology [19] is a process which enables the microorganisms in the environment to metabolize the molecular structure of plastic products into humus that is beneficial to the environment. In this technology an additives are added which combined in small quantities with any of the popular plastic resins, renders the end products biodegradable while maintaining their other desired characteristics. The plastic products made by adding such additives will break down in nearly all landfills or wherever else they may end up. All sorts of factors determine the amount of microbes available in the soil and the soil conditions determine the rate of degradation. The plastic products made with ECM technology basically rely on the microbes in the soil to react with the additives and create the enzymes and acids that can attack the long-chain hydrocarbon molecules and break them down to the point that the microbes' natural acids and enzymes are then effective and the microbes can metabolize the simple hydrocarbons with CO_2 and water or methane being the waste products. This process continues until all the plastic product is full biodegraded. This has been tested and proved as biodegradable and safe for the environment

Chemical degradation

Chemical degradation of plastics are by

i) Solvolysis: Step-growth polymers like polyesters, polyamides and polycarbonates can be degraded by solvolysis and mainly hydrolysis to give lower molecular weight molecules. The hydrolysis takes place in the presence of water containing an acid or a base as catalyst. It was the reverse reaction of the synthesis of the polymer: [20]

ii) Ozonolysis: Ozonolysis is the cleavage of an alkene or alkyne with ozone to form organic compounds in which the multiple carbon–carbon bond has been replaced by a double bond to oxygen. [21].The outcome of the reaction depends on the type of multiple bond being oxidized and the workup conditions.

iii) Oxidation: Polymers are susceptible to attack by atmospheric oxygen, especially at elevated temperatures encountered during processing to shape. Many process methods such as extrusion and injection moulding involve pumping molten polymer into tools, and the high temperatures needed for melting may result in oxidation unless precautions are taken. [20]

iv) Galvanic action: Polymer degradation may occur through galvanic action similar to that of metals under certain conditions. Plastics are made stronger by impregnating them with thin carbon fibers only a few micrometers in diameter known as carbon fiber reinforced polymers (CFRP). This is to produce materials that are of high strength and resistant to high temperatures. The carbon fibers act as a noble metal similar to gold (Au) or platinum (Pt). When put into contact with a more active metal, for example with aluminum (Al) in salt water the aluminum corrodes. However in early 1990, it was reported that imide linked resins in CFRP composites degrade when bare composite is coupled with an active metal in salt water environments. This is because corrosion not only occurs at the aluminum anode, but also at the carbon fiber cathode in the form of a very strong base with a pH of about 13. This strong base reacts with the polymer chain structure degrading the polymer. Polymers affected include bismaleimides (BMI), condensation polyimides, triazines, and blends thereof. [20]

v) Chlorine-induced cracking: Another highly reactive gas is chlorine, which will attack susceptible polymers such as acetal resin and polybutylene pipework. The gas attacks sensitive parts of the chain molecules (especially secondary, tertiary, or allylic carbon atoms), oxidizing the chains and ultimately causing chain cleavage. The root cause is traces of chlorine in the water supply, added for its anti-bacterial action, attack occurring even at parts per million traces of the dissolved gas. [20]

CONCLUSION

There are many processes of degradation of Plastics but the degradative action of microbes and additive technology has opened the way for new considerations of waste management strategies since these materials are designed to degrade under environmental conditions hence they plastics have a promising future from what they have to offer. Therefore, if traditional plastics can be replaced in every possible field, then, the issue of plastic wastes and threats they seem to pose will be resolved. Biodegradable plastics have a potential in ecofriendly management of toxic wastes and chemical pollution in future.

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