EFFECT OF PRO-DEGRADANT ADDITIVE ON BEHAVIOUR AND KINETIC DEGRADATION OF POLYPROPYLENE FILM.

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UNIVERSITI SAINS MALAYSIA

2011

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by

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LIST OF SYMBOL

^{o}C	Degree Celsius
w/w %	Weight per weight percent
cm	Centimeter
g	Gram
ρ_m	Melt density
T_m	Melting temperature
Ts	Tensile strength
E_b	Elongation at break

LIST OF ABBREVIATION

ASTM	American Standard Testing and Materials
CI	Carbonyl Index
DSC	Differential Scanning Calorimetry
FT-IR	Fourier Transform Infra Red
GCMS	Gel Chromatography Mass Spectrometer
GPC	Gel Permeation Chromatoghrapic
HDPE	High Density Polyethylene
LDPE	Low Linear Polyethylene
MFI	Melt Flow Index
PDA	Pro-degradant Additives
PET	Polyethylene Terephthalate
PP	Polypropylene
PVC	Polyvinyl Chloride
PVOH	Polyvinyl Alcohol
TGA	Thermogravimetric Analysis

KESAN ADITIF PRO-DEGRADASI TERHADAP SIFAT DAN KINETIK DEGRADASI FILEM POLIPROPILENA

ABSTRAK

Percubaan ini bertujuan untuk menghasilkan bahan plastik yang degradasi terhadap persekitaran dan berkos rendah bagi mengatasi masalah limpahan sampah dengan memperkenalkan plastik oxo-degradasi. Tujuan kajian ini untuk meneliti perubahan oxo-degradasi filem berdasarkan sifat mekanikal dan terma di bawah pengaruh aditif pro-degradasi (PDA) dengan mendedahkan filem terhadap kepelbagaian penenuaan. Campuran polipropilena (PP) dan PDA dengan pelbagai nisbah berat dari 1 hingga 5 peratus disediakan. Filem nipis yang mengandungi aditif ini disediakan melalui proses penfileman plastik. Pengaruh pemanasan, cahaya UV dan oksigen pada filem PP telah dikaji dengan mendedahkan kepada alam persekitaran, penuaan termo-oksidatif dan foto-oksidatif. Keputusan menunjukkan filem cenderung untuk merosot dengan pengurangan ketara dalam sifat tensil dan kestabilan terma. Aktiviti ini bergantung kepada tindak balas antara PP dan zarah PDA. Peningkatkan kadar penghabluran selepas penenuaan adalah disebabkan pemecahan rantai PP di kawasan amorfus. Daripada kajian ini, dapat disimpulkan bahawa pendedahan kepada foto-oksidatif lebih cenderung untuk merosot berbanding dengan termo-oksidatif dan pendedahan semulajadi. Akhir sekali, penyelidikan ini diteruskan dengan kajian kinetik degradasi dengan menggunakan model iso-penukaran Flynn-Wall-Ozawa. Daya tahan filem ditemui menurun secara dramatik bersama peningkatan peratusan kobalt stearate. Kajian menunjukkan bahawa haba dan suhu mempunyai pengaruh kuat pada jangka hayat sampel dari semua formula yang telah diselidiki. Berdasarkan nilai tenaga pengaktifan, kobalt stearate mengubah langkah penentu kadar tindak balas dalam mekanisma pemerosotan.

EFFECT OF PRO-DEGRADANT ADDTIVE ON BEHAVIOUR AND KINETIC DEGRADATION OF POLYPROPYLENE FILM

ABSTRACT

Several attempts were made to produce environmentally degradable and low cost plastic materials due to the abundance of plastic waste management by introducing oxo-degradable plastic. The aim of this research was to investigate the changes of oxo-degradable films in the presence of pro-degradant additive (PDA) based on mechanical and thermal properties by exposing to various aging. Polypropylene (PP) with various loading 1 w/w % - 5 w/w % PDA blend films were prepared. Thin films containing this additive were prepared by film process. The effect of heating, UV and oxygen on PP films in the presence or absence of this additive were investigated by undergoing natural exposure, thermo-oxidative and photo-oxidative aging. Results indicated that the films tend to degrade by significant loss in their tensile properties and thermal stability. These activities were due to the reaction of PP with PDA particles respectively. The increasing in crystallinity after aging, is due to the chain scission of the polypropylene in the amorphous region. From this work, it was found that photo-oxidative aging tend to more degradable compared to thermo-oxidative and natural exposure. Finally, this study was followed by degradation kinetic study by using Flynn-Wall-Ozawa iso-conversion model. The lifetimes of the films found to decrease dramatically with increase in the concentration of cobalt stearate thereby establishing its pro-degradant ability. Studies indicated that process temperature has a strong influence on the lifetime of all the formulation investigated. Based on activation energy, cobalt stearate was found to affect rate determine step hence mechanisms of reaction.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Plastic are man –made long chain polymeric molecules (Scott, 1999) find huge application due to its excellent properties of ease in processing. They are widely used, economical materials characterized by excellent all-round properties, easy molding and manufacturing. However, most of them are non-degradable. Consequently, thermoplastic are considered non-degradable plastic where thermoplastic is a long chain independent's structure with each other (Halim, 2000). Thermoplastic polyolefins are inert materials whose backbone consists of long carbon chains (Avella et al., 2001). These chains have very high molecular weights of hundreds of thousands versus molecular weights of 18 for water (H_2O) and 44 for carbon dioxide (CO_2).

Traditionally, polyolefins are considered as non-degradable for three reasons. First, the hydrophobic character of polyolefin makes the material resistant to hydrolysis. Secondly, the use of anti-oxidants and stabilizer during manufacturing keeps polyolefins from oxidation and degradation. Thirdly, polyolefin have high molecular weight of 4000 to 28,000. High molecular weight polymer requires extra energy to be degraded into smaller molecule with fragments. Therefore, to make polyolefins degradable, these factors have to be considered (Roy et al., 2006).

Apparently, traditional plastics are very stable and not readily degraded in the ambient environment (Chiellini et al., 2003) and it has been a target of much criticism due to its lack of degradability (Guillet et al., 1995). As a result, environment pollution from synthetic plastic has been recognized main contributor to environmental pollution. For instance, statistics published by the Unites State Environmental Protection Agency in 2009 indicated that, before recycling, approximately 236 million tons of municipal solid waste (MSW) was generated in the United State in that year, of which 11.3 % was composed of plastic (http://www.biodeg.org).

Based on the study conducted by Albertsson et al., (1987) indicated that after degradation, the molecular weight of degradable polyolefins must be less than 500. As principle for making degradable polyolefins, special additives need to be added to synthetic polyolefins so that the modified structures are susceptible to chemical degradation and photo-degradation. As a result, the long carbon chains are broken to shorter segment and their molecular weights are reduced below 500 (Halim, 2000; Bonhomme et al., 2003).

Recently, the research activities for producing degradable plastics have increased tremendously (Roy et al., 2006). There are many technologies for producing the degradable products. The technologies utilised a petrochemical which include polyolefins with pro degrading additive, biodegradable polyesters and polyvinyl alcohol (PVOH) derivatives (Doty, 2005). Other technologies use a renewable resource like cellulose, starch and vegetable oil (David and Scott, 2006). One of the product examples are shopping plastic bags which are widely used in the hyper-market. These plastics bags will disintegrate in the presence of sunlight and heat, and degrade completely in the presence of oxygen, soil, moisture and microbes (Scoot, 1999). However degradable polymer with starch content has higher impacts upon greenhouse due to methane emissions during landfill degradation. On the other hand, oxo-degradable plastic do not produce methane as they degrade. Methane is 23 times more potent for global warming than carbon dioxide (CO_2) (Guillet et al., 1995).

Oxo-degradation is defined as ‘degradation in which polymer chain cleavage is primarily due to oxidation which may be mediated by abiotic chemistry such as light, temperature and water; microorganism or a combination of both (Albertsson and Karlsson, 1990). This technology is based on a very small amount of a special additive or pro-degradant additive being introduced into the conventional manufacturing process, thereby changing the behaviour of the plastic. After these plastic are commensurate with the disposal environment. Transition metal salts are commonly used as pro-degradant additive.

The use of pro-oxidant additive makes polyolefins oxo-degradable (Guillet et al., 1995) which catalyze the breakdown the long chain of polyolefin and producing low molecular weight product such as carboxylic (–COOH), hydroxyl (-OH) and carbonyl group (C=O) containing products (Roy et al., 2006). Metals act as good pro-degradant additive in polyolefins making polymer susceptible for degradation (Osawa, 1998). To be active as catalyst, it is necessary to combine two metal ions of similar stability. Furthermore, when two metal ions are oxidized by oxidants, the oxidation number of the metal ions must be only unit different from the one before oxidation. Jakubowicz, (2003) studied the thermo-oxidative of polyethylene films during composting conditions and in the presence of pro-oxidant additive. Jakubowicz found that metal combinations were the most active pro-oxidants. For example, cobalt (Co) is a suitable metal participating in metal combination for pro-oxidant activity. As an oxidation-reduction catalyst, two Co^{2+} ions with similar stability would be oxidize to Co^{3+} and then later reduced to Co^{2+}. Thus, when polyolefins are exposed to the environment, a free radical chain in the polymer can react with oxygen from the atmosphere and produce hydro-peroxides that can, in turn, be hydrolyzed and photolyzed.

The pro-degradant additive is able to catalyze the polymer degradation completely into a small molecular weight (Doty, 2005). Firstly, pro oxidant activities can change the polymer surface from hydrophobic character to hydrophilic by introducing hydroperoxide, carbonyl and carboxylic groups (Roy et al., 2006). Secondly, pro-oxidants can catalyze the breakdown of the long chain of polymer and produce lower molecular weight products either during photolysis or thermolysis and producing low molecular mass oxidation products, such as acids, alcohols and ketones (Roy et al., 2006).

Oxidation degradation is required initially to reduce the molar mass value by an order of magnitude and concomitantly convert hydrophobic plastic into water wettable materials (Albertsson and Karlsson, 1990). The presence of the chemical, abiotic and biotic agents are able to convert polyolefin to carbon dioxide and water. The most useful and economic of the new technologies is wherein a plastic degrades by a process of oxo-degradation whereby biotic agents such as microorganisms are not necessary.

1.2 Problem statement and Research Approach

Date back to the second half of the 20th century many researchers attempted to produce environmentally degradable, low cost, plastic material from polyolefins in order to overcome disposable plastic. Their potential degradability and ultimate biodegradability started to be considered in the early 1970s (Chiellini et al., 2003) as specific attributes for applications in packaging and agricultural market segments. Figure 1.1 shows the statistic of waste pollution in the environment, where packaging contributes the highest ranking.

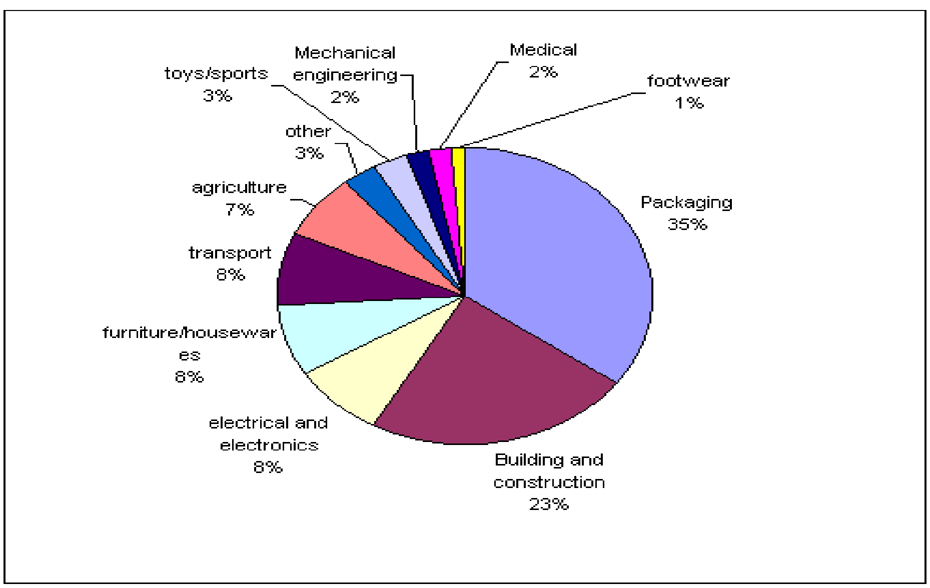

Figure 1.1: Analysis of household waste compositions and factors driving waste increases (www.epa.gov).

Recently, the recycle campaign becomes a famous method to clean up the waste and reduce the usage of natural resources like petroleum or other materials. However, this method can only reduce a small quantities and the piling of the plastic at the landfill still in critical status (Avella et al., 2001). Burning in the landfill is another choice but this technology is highly demanding in the total cost. For that reason, the degradable plastic becomes an alternative method to get rid of this problem and produces more eco-friendly plastics. Moreover, the mechanical properties of degradable plastics are still comparable with the traditional plastics (Halim, 2000).

Furthermore, oxo-mechanisms process occurs at the early stage of polymer degradation by introducing pro-degradant additive. This contributes to a shorter life-time cycle. The oxo-degradable plastics provide environmental benefits in comparison with untreated plastics (David and Scott, 2006). Thus, the remaining quantity of plastic waste is still required to be disposed. Most of the plastic waste has been accumulating in landfills. Therefore, in order to save capacity for plastic waste disposal, there is a growing interest both in the development of newer, readily biodegradable plastic and in the biodegradation of conventional plastic waste. In addition, oxo-degradable plastic does not emit methane gas as compared to other degradable plastic such as hydro degradable plastic as their degraded.

However, most of studies only covered in polyethylene degradation behaviour. Roy et al., (2006) conducted a study on the effect of various aging treatment of oxo-degradable plastic film. Polyethylene has a linear structure, while polypropylene has branching molecule structure. Therefore polypropylene degradations were studied in this research by expose to various aging conditions such as thermal, light and natural exposure.

1.3 Research objectives

The investigations of the effect of pro-degradant additive on polypropylene films are covered in this research. Efforts have been made to analyze the degradation behaviour of oxo-degradable film. Obviously, there are three main objectives targeted which are listed as follows:

1. To investigate the effect of pro-degradant additive concentration on the physical, mechanical and thermal properties of the polypropylene films.
2. To study the effect of pro-degradant additive on several degradation systems of polypropylene.
3. To study the kinetic of degradation of oxo-degradable polypropylene films.

1.4 Outline of Thesis Structure

Chapter 1: Briefly introduces oxo-degradable plastic as alternative method to produce environmental-friendly products. This chapter also covered the problem statements and objectives of the study.

Chapter 2: Contains a review of the literature on degradable plastic, types of degradable plastic, oxo-degradable plastic, advantages of oxo-degradable plastic, environmental benefits of oxo-degradable and composition of oxo-degradable plastic. This chapter also highlights various studies and published works on oxo-degradable films.

Chapter 3: Describes the details of experimental methodology, materials and equipments used throughout the experiment.

Chapter 4: Presents the experimental results where the results from the experiments are presented in charts, data tables, and micrographs. The results obtained from the experiments are evaluated and discussed thoroughly.

Chapter 5: States several conclusions of the present study and a few suggestions and recommendations for future studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Definition of degradable plastic

ASTM and ISO committee had defined a degradable plastic as a plastic designed and underwent a significant change in chemical structure under specific environmental conditions, resulting in a loss some properties that may vary as measured by standard test methods appropriate to the plastic application in a period of time that determines its classifications (ASTM D883). Degradable plastic is also known as **$d_2w^{™}$ in industry field.** Degradability is not a disposal option, but can still be reused and recycled where it is low cost insurance against the accumulation of plastic waste in the environment.

Degradable plastic includes biodegradable and bio-compostable plastic (Halim, 2000). These not biodegradable or bio-compostable plastic usually simply label as degradable plastic. Most of the products using the label **degradable plastic** degrade as a result of physical and chemical impact (fracture into smaller pieces of plastic). Biological activity is not a significant part of the degradation of these products, or the process is **too slow** to earn the classification **biodegradable** or **compostable (Grassie and Scott, 1985).**

2.1.1 Types of degradable plastic

There are several alternative methods of manufacturing a plastic material that will degrade to a number of harmless elements. The types of degradable plastic are hydro-degradable, oxo-degradable, aliphatic and photo-degradable. In industry, they are more focus on hydro- and oxo-degradable plastic. Below are the lists of degradable plastic with their cons and pros (Halim, 2000).

a) Hydro-degradable

Hydro-degradable plastic products are based on starch derived from maize. These materials predominantly require an active microbial environment such as landfill or composting before they will degrade (Baljit and Nisha, 2008). However, some of them will totally degrade in such environments but others will only perforate, and the plastic component will not degrade. The remaining plastic particles can be harmful to soil, birds and other wildlife. Whilst using renewable ingredients may seem attractive in principle, they do not offer the best way forward. The pros and cons of the hydro-degradable are listed below:-

Pros

- It is compostable under industrial conditions.
- Reduced fossil fuel content (depending on loading of filler).

Cons

- Much too expensive for everyday use and source of starch can be problematic (competition against food use, rainforests being cleared to grow crops for bioplastics)

- Fossil fuels are burned and CO_2 produced in the agricultural production process.
- Poorer mechanical strength than additive-based example – filling a starch bag with wet leaves and placing it curbside can result in the bottom falling out when a haulier picks it up.
- Often not strong enough to be used in high-speed machines
- Degradation in a sealed landfill takes at least 6 months.
- Emits CO_2 in aerobic conditions and methane under anaerobic conditions

b) Oxo-degradable

The technology is based on a very small amount of pro-degradant additive being introduced into the manufacturing process, thereby changing the behaviour of the plastic. Oxo-degradable plastic products are most useful and economical of the new technologies in producing plastic compared to other degradable plastics (Roy et al., 2006). The technology behind **d$_2$w™** totally degradable plastics introduces a pro-degradant into the polymer that acts as a catalyst and causes a rapid breakdown of the long molecular chains. The pros and cons of oxo-degradable are listed below:-

Pros

- Much cheaper than starch-based plastics
- Can be made with normal machinery, and can be used in high speed machines, so no need to change suppliers and no loss of jobs
- Does not compete against food production

- They can be recycled with normal plastics
- Like normal plastics they are made from a by-product of oil or natural gas, but these would be extracted whether the by-product were used to make plastic or not
- They are certified non-toxic, and safe for food-contact

Cons

- Degradation depends on access to air
- Not designed to degrade in landfill, but can be safely land filled. Will degrade if oxygen is present, but will not emit methane in landfill
- Time to degrade can be set during manufacturing
- Precise rate of degradation/biodegradation cannot be predicted, but will be faster than nature's wastes such as straw or twigs, and much faster than normal plastic

c) Aliphatic polyester

Another type of degradable plastic uses aliphatic polyesters, which are relatively expensive. In the same manner as starch, they rely on microbial activity in compost or landfills before they will degrade. The degradation of aliphatic polyesters proceeds by one or several mechanisms including chemical hydrolysis, microbial, enzymatic and thermal degradation (Grassie and Nisha, 1985).

The degradation proceed either at the surface (homogenous) or within in the bulk (heterogeneous) and it is controlled by a wide variety of compositional and property variable example matrix morphology, chain orientation, chemical orientation, stereo chemical structure, sequence distribution, molecular weight and distribution, the presences of residual monomer, oligomers and the other molecular weight products, size and shape of the specimen, and the degradation environment; e.g presence of moisture, microorganisms, oxygen, pH, enzyme, temperature and so on. The degradation mechanism domination depends on both the structure of the polyester and the environment it is subjected (Sudhakar et al., 2007).

d) Photo-degradable

This is a degradation that occurs when exposed to sunlight, but will not degrade in landfill, a sewer, or other dark environment. The present of UV light will provide the required energy to break down the molecular chain.

2.1.2 Oxo-degradable plastic

Oxo-degradable plastics are made from the by-product of oil refining and oil is a finite resource. Oxo-degradable plastic are developed by 'Totally degradable Plastic additive" (TDPA) formulations. The use of pro-degradant additive makes polyolefins oxo-degradable (Doty, 2005). This pro-degradant is in the form of a metal salt that causes a breakdown of the carbon-carbon bonds in the molecular chains - i.e. chain cleavage, or scission is activated. The plastic product will become brittle and quickly disintegrate into tiny flakes. As the chains continue to reduce in size, oxygen is permitted to bond with the carbon and produce CO_2 (Alauddin et al., 1995). The molecular mass quickly descends to below 40,000 Daltons and at that stage, the material effectively becomes water wettable and micro-organisms can access the carbon and hydrogen (Halim, 2000). Carbon is used for cell wall structure etc. and it is exhausted as CO_2 and the hydrogen as H_2O. This stage can accurately be described as bio-degradation.

The pro-degradant is introduced at the extrusion stage of manufacture, when polymer granules are heated and melted to form packaging films. The **d_2w**™ additive itself is provided as a masterbatch and only a small amounts are required to cause the degradation reaction. In percentage terms, only between 1 to 3 % is typically required. Degradation is triggered by the extrusion process but is sufficiently slow during the initial stages of the scission for it to have no effect on the properties of the film. Stabilisers are also included in the additive masterbatch that protect the pro-degradant throughout the melting process, and then determine the time scale to the onset of the degradation process. Therefore, different periods of fit for purpose can be engineered depending on the final application of the material.

Various studies have been conducted to understand the degradation behavior of polyolefin films using pro-degradant additive such as Roy et al., (2006) who has done extensive investigation of low linear polyethylene by introducing various types of metal additives.

2.1.3 Differences between oxo-degradable and oxo-biodegradable plastic

By definition 'oxo-degradable plastic' means a plastic film containing a controlled percentage of an appropriate non-toxic, non-tinting additive, which will enable the plastic film to totally degrade by oxidation process in natural aerobic (composting) including disposed in anaerobic environments (landfill) or other regulated dumping area within such period of time as specified (Baljit and Nisha, 2008). The differences between term biodegradable and degradable refer to an attack by microorganisms such as bacteria, fungi and algae on nonwater-soluble polymer-based materials (plastics) (Halim, 2000). The plastic will degrade because of bacterial activity known as biodegradable plastic. This implies that biodegradation of plastics is usually heterogeneous process. However, in oxo-degradable process does not requires any biological agents such as microorganisms in their oxidation and degradation activity for plastic to degrade, thus the plastic is known as degradable plastic.

2.1.4 Advantages of oxo-degradable plastic

Because of their relatively affordable, plastic incorporating oxo-degradable technology are used in common commodity type applications and readily replace conventional packaging. The oxo-degradable plastic will degrade in any outdoor or indoor environment where air is present, even in the absence of water. They biodegraded and can be composted but they do not need to be buried in a compost heap or landfill in order to degrade. They will degrade in a normal environment in the presence of oxygen and temperature. This is a very important factor in relation to litter, because a large amount of plastic waste on land and sea cannot be collected and buried. Besides that, they are stronger and more versatile, and can also be used for direct food contact, but they will degrade better as well.

The degradation process of oxo-degradable plastic can be programmed by controlling the life span of the products. While the rate of photo and starch based cannot be controlled. The length of time either in a short period or long period of a few years of polymer takes to degrade can be programmed at the time of manufacture. There is little or no additional cost involved in products made with this technology.

2.1.5 Environmental benefits of oxo-degradable plastic

As mention on the last sub chapter, oxo-degradable plastic has many advantages compared to the other types of degradable plastics. The advantages of oxo-degradable plastic to the environment can be seen clearly as mention in next subtopic. Figure 2.1 shows the natural recycle of oxo-degradable plastic. Oxo-degradable is environmental friendly as they do not emit methane gas as they degrade. There are several areas where oxo-degradable plastic can have a major beneficial impact on the environment in terms of litter, landfill and compost.

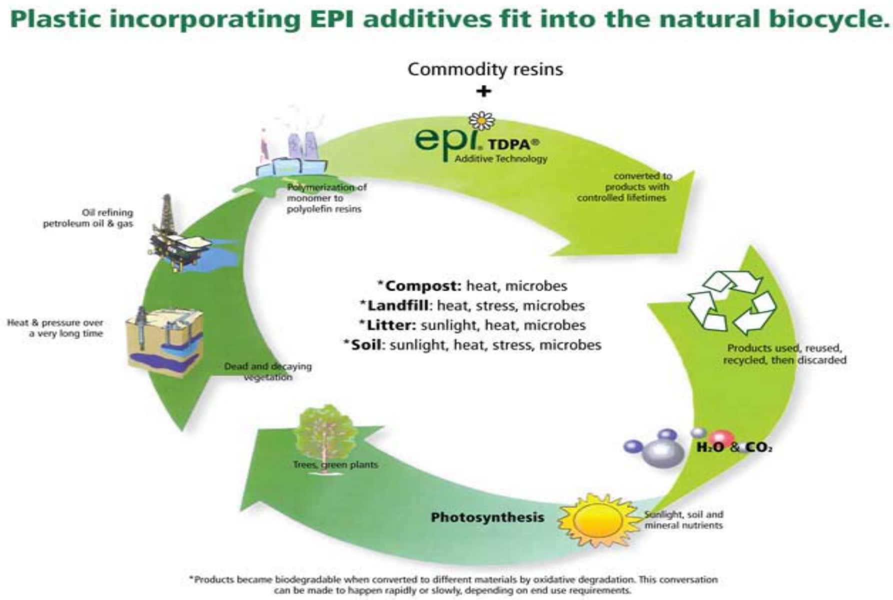

Figure 2.1: Natural recycles of oxo-degradable plastic (www.biodeg.org)

2.1.5.1 Litter

Discarded conventional plastics remain in the environment for many decades, and are often possible to collect, composting and recycling. Oxo-degradable plastic will degrade and disappear, leaving no harmful residues if they are not collected. Exposure to the sunlight can accelerates the degradation rate and once it is initiated, the process of oxo-degradation continues in the absence of light, so long as air is present. Hydro-degradable plastics will not readily degrade unless they are in a highly microbial environment and will instead merely fragment (Norman et al., 2003). Because of this behavior, oxo-degradable are considered as the best solution in degradable plastic manufacturing.

Suppose for the sake of environmental issues, if 1000 conventional and 1100 oxo-degradable plastic bags are left uncollected in the environment, 1000 conventional bags will remain in the river causing float and fields for decades, but none of the oxo-degradable bags will be left at the end of the short life programmed. Besides that, paper bags are counted as an alternative to manufacturing of degradable plastic. However, the process of making paper bags causes 70 % more atmospheric pollution than plastic bags. Paper bags use 300 % more energy to produce and the process uses huge amounts of water and creates very unpleasant organic waste (Tavares et al., 2003).

2.1.5.2 Landfill

Another advantage of oxo-degradable plastic is it will continue to degrade if put into landfill with brick, concrete, metal, conventional plastic and other non-organic materials. They are fragment and partially degrade to carbon dioxide and water in the surface layers of the landfill, but the residues are completely inert deeper in the landfill in the absence of oxygen. By contrast, hydro-degradable plastics will degrade and emit carbon dioxide in the surface layers of a landfill if there is enough microbial activity (Briassoulis et al., 2004). However, in the depths of landfill, in the absence of air, hydro-degradable plastics generate copious quantities of methane, which is powerful greenhouse gas. Conventional plastic bags take up more space in a landfill because they trap air and do not readily disintegrate thus inhibit the decomposition of their content in the landfill.

2.1.5.3 Recycling

Oxo-degradable plastics can be recycled with other clean commercial polyolefin wastes, provided that regard is had to be inclusion rate and the level of degradation and stabilizer are added when necessary. After cleansing, separation and re-extrusion the degradation process is arrested, and the recycled plastic reverts to the properties of conventional plastics. Interestingly, as a further option, the additive can be added to recycle the plastic and that will cause it to degrade in turn if that is the required outcome. Roy et al., (2006) conducted study on photo-oxidative degradation of LDPE films in the presence of oxidized polyethylene. The results shows, photo-degradation of polyethylene can be accelerated using thermally degraded. However, hydro-degradable plastic cannot be recycled with other polymer components of waste. The plastic have to be extracted from the waste stream and treated separately, at prohibitive cost.

2.1.5.4 Composting

Organic waste can be put into oxo-degradable plastic sacks in homes, restaurants, hospitals, and put straight into the composting plant without the messy and expensive business of emptying the sacks and disposing of them separately. Disease transmission by flies and rats handling hazards to human are effectively minimized by the use of such sacks. The resulting compost is valuable resource for farmers and growers, and since oxo-degradable plastics release its carbon slowly, it produces high quality compost.

2.1.6 Safety of oxo-degradable plastics

Oxo-degradable plastics were claimed by reputable testing agencies that it is non toxic. It has been important to establish that nothing harmful to the environment is generated or left behind by the use and disposal of polypropylene with controlled environmental degradability. It should be noted that the additives used to promote preoxidation of oxo-degradable polyolefins do not alter the normal oxidation chemistry of these materials but only speed up the slow rate determining of the individual reactions. Cobalt metal is widely used in oxo-degradable plastic. It should be understood that trace elements are necessary for human growth and healthy plant required cobalt and manganese as dietary supplement. An expert group on Vitamins and Minerals of the UK Food Standard Agency found that high concentration of cobalt was found in fish, nuts and fresh cereals. The only toxicity data for cobalt reported is cobalt chloride (Herbert, 1996).

2.1.7 Degradable polymer application

Two different applications were introduced over two past decades for degradable polymers. The first is degradability is part of the function of the product. Degradable polymer was widely used in agricultural and pharmacology (medicinal drug). The second application is in packaging. Oxo-degradable is now emerging as a more convenient alternative to recover and improve waste packaging management.

2.2 Polypropylene

Polypropylene (PP) is among remarkable thermoplastic resin in packaging application. Polypropylene is a strong, low density polymer which exhibits outstanding resistance to heat, good surface characteristics (hardness, gloss, rigidity etc.) excellent mechanical properties and low taste and odor with representing of molecular formula $(C_3H_6)_n$. Figure 2.2 represents the chemical structure of polypropylene.

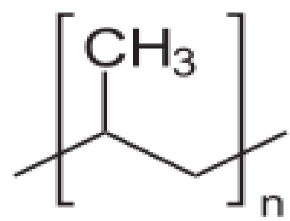

Figure 2.2: Chemical structure of polypropylene (Guillet et al., 1995).

Most commercial polypropylene is isotactic and has an intermediate level of crystallinity and Young Modulus between low density polyethylene (LDPE) and high density polyethylene (HDPE). The tensile strength of polypropylene was unchanged during exposure to the environment (Grassie and Scott,1985). Polypropylene is normally tough and flexible. This allows polypropylene to be used as an engineering plastic, competing with materials such as ABS. Polypropylene is reasonably economical, and can be made translucent when uncolored but is not as readily made transparent as polystyrene, acrylic or certain other plastics. It is often opaque or colored using pigments. Polypropylene has good resistance to fatigue and has a melting point of 160 °C (320 °F). The melt flow rate (MFR) or melt flow index (MFI) result can determine the changes value in molecular weight of polypropylene. The measure helps to determine how easily the molten raw material will flow during processing. Polypropylene with higher MFR will fill the plastic mold more easily during the injection or blow molding production process. As the melt flow increases, however, some physical properties, like tensile strength, will decrease.

Some of the features that make polypropylene valuable sheet extrusion are strength and lightweight with a specific gravity of 0.90 - 0.91 where polypropylene has the lowest density of all the commodity thermoplastics. Its high strength to weight ratio makes it attractive in many applications requiring greater rigidity than that possible using other polyolefins. Polypropylene has better heat resistance than any other low cost thermoplastic. At both ambient and elevated temperatures polypropylene exhibits excellent resistance to direct attack from non-oxidizing inorganic chemicals, detergents, low boiling hydrocarbons and alcohols. However, caution should be exercised in the presence of halogenated solvents and hydrocarbons, which may permeate and soften polypropylene. Polypropylene is normally not susceptible to environmental stress cracking.

In general homopolymers (only one type of monomer) can be used for housing, housewares, packaging, cassette holders and fibers, monofilaments and film tapes while copolymers (different monomers are involved) are preferred for all applications exposed to cold and they are widely used for pipes, containers, boat hulls, seat shells and automotive parts for example; battery cases and bumpers. Polypropylene can be manufactured to a high degree of purity to be used for the semiconductor industry. Its resistance to bacterial growth makes it suitable to be used in medical equipment.