

A Review on Processing of Waste PET (Polyethylene Terephthalate) Plastics

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Abstract

Solid waste is essentially waste produced in our homes, businesses and industrial sources. Globally waste production is growing in volume and in toxicity. Plastic waste is a nature threat that is of great concern to the researches to refuse and reuse. The man-made systems emphasize the economic value of materials and energy where production and consumption are the extensive economic actions. Such systems are a threat to the environment as they require maximum consumption of capital energy and the end product waste returned to the environment, is in a form that damages the environment and requires more natural capital in order to feed the system. Hence balance in the ecosystem is to be maintained with great burden. This problem is because of the sheer volume of waste being produced. Utilization of recycled Polyethylene Terephthalate, polycarbonate and melamine in the concrete composite are rarely processed. The plastic bottles broken to granules or into small (PET) particles and used as sand-substitution aggregates in cementitious concrete composites which appear to offer an economical material with consistent properties. The importance of this review is to study the properties of waste PET plastics, processing techniques and its reuse as composite laminates an alternative to wood requirement.

Keywords: composite, laminates, processing, properties, PET

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INTRODUCTION

Plastics are polymers of organic molecules. Plastic materials can be melted into different shapes by using variety of processes, such as spinning, molding, extrusion, or casting. Plastics are inexpensive, lightweight, strong, durable, corrosion-resistant materials, with high thermal and electrical insulation properties. The diversity of polymers and their unique properties are used to make a variety of products that advances its applications in medicine, engineering, energy savings and other society benefits. Some extremely desirable characteristics are found in Modern plastics such as good thermal properties, high resistance to acid,

solvents, alkalis, high strength-to-weight ratio, electrical insulation, flexibility, stress resistance and durability. Plastics are polymer of many repeated units of monomer molecules. Based on the structure the polymer can be differentiated and its characteristics can be determined. Linear polymers consist of single linear chain of monomer; branched polymers are linear with side chains and are thermoplastic that is they soften when heated and Cross-linked polymers are polymers with bond formed between polymer chains are thermosetting, that is they harden when heated. Due to these properties the plastics are widely used in every field.^[1] There is an increase use of

plastics over 60 decades from 0.5 million tonnes in 1950 to over 260 million tonnes today. The plastic industry In Europe alone has a turnover in excess of 300 million euros and about 1.6 million people are employed. The aspects of daily life involve the use of plastics, in transport, telecommunications, clothing, footwear and as packaging materials that facilitate the transport of a wide range of food, drink and other goods. There is considerable potential for new applications of plastics that will bring benefits in the future, for example a new invention in medical applications, in the generation of renewable energy and by reducing energy used in transport.^[2] Typically the polymer resins are mixed with various additives to improve performance. These additives

include inorganic fillers such as carbon and silica that reinforce the material, plasticizers to render the material usable, thermal and ultraviolet stabilizers, flame retardants and colorings. Many such additives are used in substantial quantities and in a wide range of products. Some additive chemicals are potentially toxic (for example lead and tributyl tin in polyvinyl chloride, PVC).^[3,4] The amount of plastic waste as drastically increased due to its continuous use, hence recycling and reusing of plastic waste is necessary.^[3] Globally there is increase in production of plastic by an average rate of 9% since 1950 to a peak of 245 million tonnes in 2008, after which there was a slight drop in production.^[1]

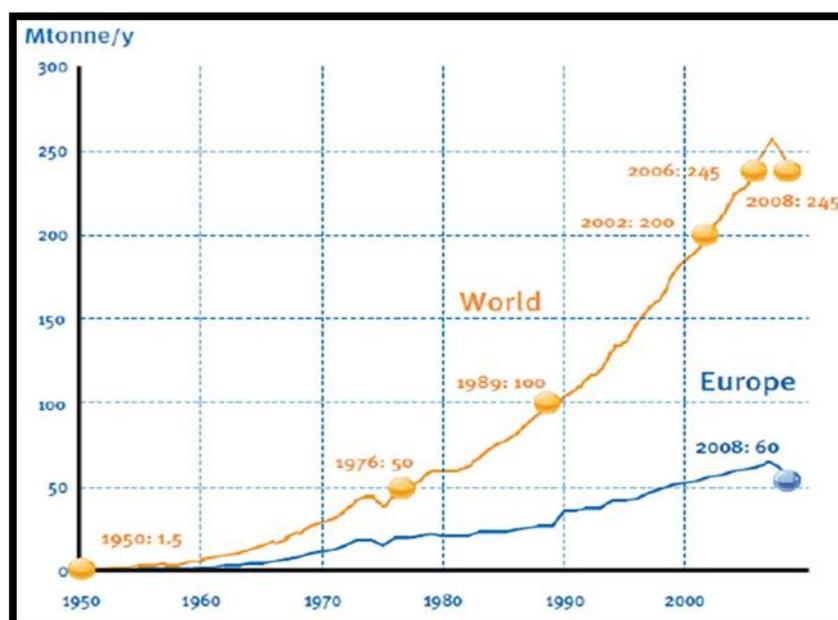


Fig. 1. Graph Which Indicates the Global Increase in Plastic Production From 1950.^[1]

REUSE

Some of them plastic and glass containers are cleaned and reused. It is not widely practiced, the plastic packaging of many products are thrown after first use. However, there are examples of reuse in them marketplace. For example, a number of detergent manufacturers market refill sachets. Consumers can refill and reuse their plastic bottles at home, but these

applications cannot be extended to food processing units or food storing containers. General methods are: reuse, mechanical recycling, and chemical recycling.^[3,5]

Mechanical Recycling

It is known as physical recycling. The basic structure of the material of waste plastics is unaltered and recycled into valuable resources. It includes: (a) direct

recycling to virgin plastic (i.e. high value end-product). This method yields good quality products and (b) down-cycling (i.e. low value end-product low quality plastics product is obtained).

Chemical Recycling

Commonly known as feedstock recycling. This method involves the breakdown of polymer into their constituent monomer units which can be reused in petrochemical and chemical production. The chemical recycling is carried out either by pyrolysis or by solvolysis.^[6]

Large quantities of plastics have been accumulated in the natural environment and landfills. Municipal waste stream contains about 10% by weight plastic. Littered plastics contaminate a wide range of terrestrial and marine habitats also highest mountains. There are also some data on waste in the urban environment. There are accounts of contamination of soils with small plastic fragments as a result of spreading sewage sludge of fragments of plastic and glass contaminating compost prepared from municipal solid waste and of plastic being carried into streams, rivers and ultimately the sea with rain water and flood events. The amount of plastic debris in ocean has risen comparatively. These fragments accumulate as microplastics. This is about 5 mm in diameter.^[7] Microplastics can be of primary (purposefully manufactured to be of microscopic size) or secondary (derived from the fragmentation of macroplastic items) origin.^[8] Fragments as small as 1.6 mm have been identified in certain marine habitats and also smaller pieces below current levels of detection.^[7,4]

EFFECTS OF PLASTIC DEBRIS IN THE ENVIRONMENT AND ON WILDLIFE

Plastic debris causes aesthetic problems,

and it also presents a hazard to marine activities including fishing and tourism. Discarded fishing nets result in ghost fishing that may result in losses to commercial fisheries. Over 260 species, including invertebrates, turtles, fish, seabirds and mammals, have been reported to ingest or become entangled in plastic debris, resulting in impaired movement and feeding, reduced reproductive output, lacerations, ulcers and death.^[9] Uptake of contaminants by organisms occurs by a variety of common pathways, most commonly inhalation, dermal sorption and ingestion. Contaminant transfer to organisms from plastics may occur by any of these routes, and the major transport route will vary according to the organism and the physico-chemical properties of the contaminant. For most species, the predominant route of transfer of contaminants from plastics is likely to occur via plastic ingestion.^[10] The limited monitoring data we have suggest rates of entanglement have increased over time. A wide range of species with different modes of feeding including filter feeders, deposit feeders and detritivores are known to ingest plastics. However, the ingestion is likely to be particularly problematic for species that specifically selected plastic items because they mistake them for their food. As a consequence, the incidence of ingestion can be extremely high in some populations. For example, 95% of fulmars washed ashore dead in the North Sea have plastic in their guts, with substantial quantities of plastic being reported in the guts of other birds, including albatross and prions.^[11]

Effects on Humans

Plastics have adverse effect on human health and a growing risk factor. Chemicals used in plastics manufacturing process are toxic. Biomonitoring (e.g. measuring concentration of environmental contaminants in human tissue) measures

an organism's exposure to elements from multiple sources. This showed toxic chemicals used in the manufacture of plastics are present in the human population and the research studies on model organisms indicate potential adverse health effects of these chemicals. This approach has also demonstrated phthalates, BPA and other additives in plastics and their metabolites present in human race. These data indicate differences according to geographical location and age, with greater concentrations of some of these chemicals in young children causing health hazards.^[12] There has been controversy over the use of PET in our containers could be harmful to our health or not. Phthalates are known to disrupt the endocrine system, which is essential in growth and development are used as a catalyst in the manufacture of PET. When taken in small quantities can cause

dizziness and depression; while in large doses can cause nausea, vomiting and even death.^[2]

ABOUT PLASTIC

A plastic material may be synthetic or semi-synthetic organic solids that are malleable. Plastics that are organic polymers are of high molecular mass but often contain other substances. The synthetic are most commonly derived from petrochemicals but are quite partially natural.^[6]

Types of Plastic and Its Classification

Plastics are broadly classified into six major types as shown in Table 1, namely, PET (polyethylene terephthalate), HDPE (high density polyethylene), PVC (polyvinyl chloride), LDPE (low density polyethylene), P/P (polypropylene), and P/S (polystyrene).

Table 1. Different Types of Plastic.^[6]

Type of plastic	Utilization
Polyethylene terephthalate (PET) 	Developed in 1941. PET has diverse application. It is a good and stable material hence can be used as a container for beverages, food and other application. Uses – Bottles, PET fibers for clothing and carpets, food containers and engineering plastics for precision-molded parts.
High density polyethylene (HDPE) 	Developed and mass-produced since 1939. Slightly opaque, low gloss, crackly film. Uses – Milk bottles, supermarket bags. Blow-molded beverage bottles, toys, gas tanks, fibers for clothing, etc.
Polyvinyl chloride (PVC) 	Developed and mass-produced since 1938. Uses – Electrical or electronic, packaging, pipes and fittings, wire and cable insulation, medical applications, etc.
Low density polyethylene (LDPE) 	Developed and mass-produced since 1939. Flexible, not crinkly. Uses – bread bags, Blow-molded beverage bottles, toys, shrink wrap.
Polypropylene (PP) 	Developed and mass-produced since 1950s. Uses – Polypropylene plastic has resistance to water, salt and acid solutions. Hence used as medicine bottles, medical syringes, ketchup bottles, yogurt containers, automobile battery casings, automobile battery casings, beakers, and carpeting markets.
Polystyrene (PS) 	Developed and mass-produced since 1930. Uses – Packaging material, safety razors, pens, electrical or electronic uses, jewel boxes and building or construction flatware.
Acrylonitrile-butadiene-styrene (ABS) 	Developed and mass-produced since 1960s. Uses – Electronic housings, computer housings (electroplated on the inside), telephone components, pipes and fittings, as well as automobile interior and exterior trim.

About PET (Polyethylene Terephthalate) Plastic

According to IUPAC polymer nomenclature, the systematic structure based name of this polymer is poly(oxyethylene oxyterephthaloyl). The common name is poly(ethylene terephthalate) and the abbreviation commonly used in literature is PET or PETP. The commonly used trade names for PET fiber products are Amilon (Brazil), Yambolen (Bulgaria), Terital (Italy), Teton (Japan), Elana (Poland), Dacron (USA), etc.^[9,13]

PET abbreviated as polyethylene Terephthalate is a long-chain polymer belonging to the generic family of polyesters. PET is formed from the intermediates, terephthalic acid (TPA) and ethylene glycol (EG), which are both derived from oil feedstock. There are other polyesters based on different intermediates but all are formed by a polymerization reaction between an acid and an alcohol. PET, in its purest form, is an amorphous glass-like material. Under the influence of direct modifying additives it develops crystallinity. The crystallinity is developed by heat treatment and melt. Originally patented and exploited by DuPont during the search for new fiber-forming polymers, polyester fiber applications have developed to such an extent that PET represents over 50% of world synthetic fiber manufacture. PET is used alone or blended with cotton or wool to impart better wash/wear and crease resistant properties to textiles. In the late 1950s PET was developed as a film. It was first used for video, photographic and X-ray films in addition to uses in flexible packaging. Later that PET was modified for use in injection molded and extruded articles, primarily reinforced with glass fiber. In the early 1970s PET was stretched by blow molding techniques which produced the first oriented three

dimensional structures initiating the rapid exploitation of PET as lightweight, tough, unbreakable bottles.^[10,14]

MANUFACTURE OF PET PLASTIC

Polyesters are made by the reaction of bi-functional acids and alcohols, in the presence of a metal catalyst. The key polymerization step is known as a condensation reaction in which molecules react and release a simple by-product. This is followed by a second polymerization reaction, which occurs in the solid phase. For manufacture of PET the intermediates, pure terephthalic acid (TPA) and ethylene glycol (ethanediol), are derived from crude oil. When heated together the first product is a monomer (BHET – bis-hydroxyethyl-terephthalate) mixed with low molecular weight polymers (oligomers). The mixture then reacts with further, distills out excess ethylene glycol and forms the PET as shown in Figure 1. At this stage the PET is a viscous molten liquid. It is extruded, and water quenched to form a glasslike amorphous material. Some PET is also manufactured using technology based on the dimethyl ester of terephthalic acid (DMT). The required of high molecular weight PET is manufactured by a second polymerization stage carried out in the solid state at lower temperatures. This main effectively removes all volatile impurities, like acetaldehyde, free glycols and water. The high molecular weight is essential for good mechanical properties providing stiffness, toughness and creep resistance while, at the same time, giving sufficient flexibility to resist bursting and breaking under pressure (Figure 2).^[10,15]

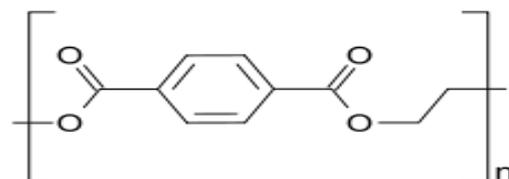


Fig. 2. Polyethylene Terephthalate Monomer Unit.

Properties of PET Plastic

Similarly to other thermoplastic polyesters, PET products are tough, especially the unfilled materials that show no breaks in the unnotched impact strength test at low temperatures (approximately $\sim 40^\circ\text{C}$). The tensile strength and flexural modulus decrease with the temperature rise but still allow use in a number of applications requiring exposure to elevated temperatures.

PET is distinguished by excellent performance under static and dynamic loads, retaining dimensional stability even at elevated temperature. The surface of molded PET is glassy, hard, and abrasion-resistant, with low coefficients of friction.

PET has low moisture absorption, allowing the material to maintain excellent dimensional stability through extremes of temperature and high humidity. Because of its good electrical insulation properties, PET has found use in many electrical applications.^[7,16] PET exhibits interesting physical properties (morphology). PET, in its purest form, is an amorphous glass-like material. Under the influence of direct modifying additives it develops crystallinity. Also, crystallinity can be developed by heat treatment of the polymer melt.

PET is classed as a semi-crystalline polymer and when heated above 72°C changes from a rigid glass-like state into a rubbery elastic form where the polymer molecular chains can be stretched and aligned in either one direction to form fibers, or in two directions to form films and bottles. Because of its rather high transition temperature only a limited amount of crystallization can occur during cooling after injection molding poly (ethylene terephthalate).

Such moldings are transparent and amorphous and are of little value. If the material melt is cooled quickly, while still

held in the stretched state, then the chains are frozen, with their orientation remaining intact. Once set in this stretched state the material is extremely tough and confers the properties we see in a typical PET bottle.

Usually the modifications are of a chemical nature to make manipulation of the PET between different forms easier. If the PET is held in the stretched form at temperatures above 72°C its slow manipulation between each of these forms generates a wide range of different products, which are all variants of the same basic chemical formula of PET. The PET described so far is the simplest typical product. However, many modifications are introduced to develop specific properties for the various packaging applications and to suit particular manufacturing equipment. Crystalline forms easier.

For example, small concentrations of an appropriate co-monomer (isophthalic acid – IPA or 1,4-cyclohexane-dimethanol) slow down the rate of crystallization and allow the manufacture of thicker bottle walls, sheets and films. A typical example would be in the heavier, thicker bottles used for refillable container systems. There is also a requirement to extend the rate of crystallization to restrict movement and deformation at elevated temperatures, for example in ovenable food trays. In this case a nucleating agent or crystallization promoter is employed and the molecular weight is increased. PET is becoming the package of choice for many food products, particularly beverages and mineral waters.

The main reasons for its popularity are the properties of glass-like transparency coupled with adequate gas barrier properties for retention of carbonation. Also it exhibits a high toughness/weight property ratio which allows lightweight, large capacity safe unbreakable containers.^[8] The properties of the PET plastics are listed in the Table 2.^[10,17]

Table 2. Properties of Pet Plastics.^[10]

Properties	Values
Molecular formula	$(C_{10}H_8O_4)_n$
Molar mass	Variable
Density	1.38 g/cm ³ (20 °C), amorphous: 1.370 g/cm ³ , single crystal: 1.455 g/cm ³
Melting point	>250 °C
Boiling point	>350 °C (decomposes)
Solubility in water	Practically insoluble
Thermal conductivity	0.15–0.24 W/m/K
Refractive index	1.57–1.58
Specific heat capacity C	1.0 kJ/(kg K)

Recycle of PET Plastics

Mechanical Recycling

Recycle of PET plastic is essential in future because of its nonbiodegradable property. The recycling of PET plastics can be done in different methods and they are Mechanical recycling, Chemical recycling and Energy recovery.^[11,18]

The mechanical recycling of plastics is carried out in a five step process

- (1) **Plastics collection** – Plastics for recycling come from two main sources: postconsumer plastics and postindustrial plastics. Postconsumer plastics are those which have already been used by people. These are the plastics collected in plastics recycling bins and at domestic roadside collections. Postindustrial plastics, on the other hand, are rejects from industry off cuts, damaged batches etc. These plastics are collected either directly from the industry or collected by the local council, squashed into bales and sold to a recycler.
- (2) **Manual sorting** – In theory, every type of plastic can be recycled. In practice in New Zealand only codes 1 (PET) and 2 (HDPE) are recycled. The incoming plastic is manually sorted into these two codes and 'other', and the three separate streams sent off to be chipped. It is particularly important that all PVC is removed from the PET stream as the more sophisticated sorting used later on cannot

differentiate between these two types of plastic. Any rocks, nails, metal etc. that is mixed in with the plastic is also manually removed at this stage.

- (3) **Chipping** – Each sorted stream of plastic is then sent separately to a chipper. This is a cylinder of blades somewhat like an old-fashioned lawnmower in a vessel with a 10 mm grill floor. The blades cut the material until it is small enough to fall through the grill.
- (4) **Washing** – The chips are then washed to remove glue, paper labels, dirt and any remnants of the product they once contained. Both the "other" stream and the PET stream are washed at around 90 °C for at least twelve minutes, while the HDPE (which has a much lower melting point) must be washed below 40 °C to prevent discolorations. The wash solution consists of an alkaline detergent in water, which removes dirt and grease and degrades protein. The detergent used is an alkaline, cationic detergent (i.e. an alkaline solution containing a cationic surfactant). Dishwashing detergents are usually anionic, because glass, china etc. usually build up a negative surface charge. This means that positively charged dirt particles are attracted to them, so an anionic detergent is needed to remove the dirt. If a cationic surfactant were used it not only would be incapable of removing the dirt, but it would itself stick to the surface to be cleaned, making it greasy. However, plastics acquire a positive surface charge, meaning that a cationic detergent is needed to clean them. Cationic surfactants are much less common than anionic ones, but they are used for shampoos and for fabric softeners.
- (5) **Pelleting** – This is done by melting the chips and extruding them out first through a fine grill to remove any solid

dirt or metal particles that have made it through the treatment thus far and then through a die of small holes. If the plastic was simply allowed to extrude from these holes it would come out as spaghetti-like strings and quickly tangle together. However, it is sprayed with water as it comes out (to prevent the plastic from sticking together) and cut off by rotating knives to give small, oval pellets.

The pellet of PET thus formed is melted to produce other substance such as fibers, stationary materials, parts of automobile, plastic pillars, etc. (Figure 3).^[12,19]



Fig. 3. Mechanical Recycling of PET Plastic.^[12]

Chemical Recycling

In chemical recycling, PET polymer is broken down into monomers or oligomers via various depolymerization technologies. Chemical recycling is more expensive than mechanical recycling. It usually requires a large scale in order to become economically feasible. The important advantage of chemical recycling is that the quality of virgin PET can be achieved.^[11,20] Chemical recycling of PET waste consist of depolymerization by hydrolysis, methanolysis, glycolysis and aminolysis to obtain various monomers.^[14,21]

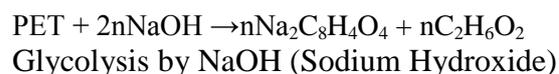
Hydrolysis

The hydrolysis of PET in presence of acid and base using suitable solvents can be

done. Neutral hydrolysis of waste PET with different amounts of water and different catalysts, in presence of xylene can be done.^[14,22,23]

Glycolysis

The glycolysis of PET yields the oligomer bis-hydroxyl ethylene terephthalate (BHET). The process is usually conducted in a temperature range between 180 and 250 °C with excess EG and in the presence of catalysts (acidic or basic). After the glycolysis process, the oligomer passes through a fine filtration step before it is repolymerized into PET.



Methanolysis

In methanolysis, PET is depolymerized with methanol to DMT (dimethyl terephthalate) and EG in the presence of catalysts under a pressure of 2–4 MPa and a temperature of 180–280 °C. The reaction mix is cooled and DMT is recovered from the mix via precipitation, centrifugation and crystallization. The recycled polymer is then converted into fiber via spinning and finishing processes. Supercritical methanol can also be used PET depolymerization instead of vapor methanol.^[13,14,24]

Aminolysis

It is another method of chemical recycling of PET waste, which has been little explored as compared to other technique. In this method bis (2-hydroxy ethylene) terephthalate (BHETA) produced by aminolysis of PET waste.

The excess of ethanolamine is used in the presence of different simple chemicals, namely glacial acetic acid, sodium acetate and potassium sulfate, as catalyst. The good yield of BHETA (91%) is obtained by this method.^[14,15,25]

APPLICATION OF RECYCLED PET PLASTIC

From an ecological point of view it is favorable to reduce the amount of plastics, thereby saving fossil resources. Despite those plastic products, including packaging materials, become thinner, the world plastics demand has been increasing yearly, making the reuse of plastic products as often as possible the most favorable option. If the plastic ends up as waste, three options are possible: landfill, energy recovery and mechanical recycling of plastics. However, from an economic point of view, there are several issues that need to be considered. However, the processing costs are higher for recycled materials. Separation, sorting, washing, drying, transportation, reprocessing; it all adds up to the cost price of a recycled plastic pellet.^[16,26]

Polyethylene terephthalate (PET) is the most widely used plastic material in the world for manufacturing secondary products such as beverage bottles. However, PET bottles are commonly

thrown away after a single use, which contributes to significant environmental problems. Therefore, methods to recycle PET bottle waste have been examined in order to improve PET recycling applications. The use of PET plastic fibers recycled from PET bottle waste in construction projects has been actively studied. Short PET fibers can be utilized to effectively reduce shrinkage strain and to enhance the ductility of concrete, especially to mitigate the inherent shrinkage problem of concrete (Figure 4).^[21,27]

Various products can be manufactured from recycled PET-bottles like

- (i) Textile fibers.
- (ii) Multi-layer or laminated food-contact containers.
- (iii) Full-contact food packaging containers (including beverage containers).
- (iv) Parts of automobiles.
- (v) Stationary items (scale, sharpener, etc).
- (vi) House hold items (trays, box, containers, etc.).^[22]



Fig. 4. Various Product Obtained From Recycled PET Plastic.^[22]

FUTURE ASPECTS

Alternatives (Biodegradable Plastics)

Biodegradable polymers (BDPs) or biodegradable plastics refer to polymeric materials that which are capable of

undergoing decomposition into carbon dioxide, methane, water, inorganic compounds, or biomass in which the predominant mechanism is the enzymatic action of microorganisms, that can be

measured by standardized tests, in a specified period of time, reflecting available disposal condition. Initial steps may involve abiotic (thermal, photo) and biotic processes to degrade the polymer, under suitable conditions, to a low-molecular weight species. However, the resultant breakdown fragments must be completely used by the micro-organisms; otherwise there is the potential for environmental and health consequences.^[17,28]

Depending on their origins, BDPs may be classified as being either bio-based or petrochemical-based. The former are mostly biodegradable by nature and produced from natural origins (plants, animals, or micro-organisms) such as polysaccharides (e.g. starch, cellulose, lignin, and chitin), proteins (e.g. gelatine, casein, wheat gluten, silk, and wool) and lipids (e.g. plant oils and animal fats). Natural rubber as well as certain polyesters either produced by micro-organism/plant (e.g. polyhydroxyalkanoates and poly-3-hydroxy-butyrate) or synthesized from bio-derived monomers [e.g. polylactic acid (PLA)] fall into this category. Petrochemical-based BDPs such as aliphatic polyesters (e.g. polyglycolic acid, polybutylene succinate and polycaprolactone (PCL)), aromatic copolyesters (e.g. polybutylene succinate terephthalate) and vinyl alcohol) are produced by synthesis from monomers derived from petrochemical refining, which possess certain degrees of inherent biodegradability. This classification differentiates between renewable (bio-based) and non-renewable (petrochemical-based) resources, but it should be noted that many commercial BDP formulations combine materials from both classes to reduce cost and enhance performance. Biodegradable plastics, therefore, often comprise polymer blends that contain partly biogenic (renewable) carbon derived from biomass and partly petrochemical carbon. Current production capacity for

biodegradable plastics worldwide is around 350,000 tonnes, representing less than 0.2 percent of petrochemical-based plastic, at approximately 260 million tonnes. However, the environmental performance benefits are insufficient on their own to enable bioplastic polymers to be more widely used as alternatives to conventional plastics. They also need to be cost-effective, fit for purpose and, ideally, provide unique benefits in use. Hence, bioplastic polymers have not yet realized their full potential.^[17,29]

Biodegradable plastics are seen by many as a promising solution to this problem because they are eco-friendly. They can be derived from renewable feedstocks, thereby reducing greenhouse gas emissions. For instance, PolyHydroxyAlkanoates (PHA) and lactic acid (raw materials for PLA) can be produced by fermentative biotechnological processes using agricultural products as well as microorganisms. Biodegradable plastics offer a lot of advantages such as increased soil fertility, low accumulation of bulky plastic materials in the environment (which invariably will minimize injuries to wild animals), and reduction in the cost of waste management. Furthermore, biodegradable plastics can be recycled to useful metabolites (monomers and oligomers) by microorganisms and enzymes. A second strategy involves degradation of some petroleum-derived plastics by biological processes. A typical example can be seen in the case of some aliphatic polyesters such as PCL and PBS that can be degraded with enzymes and microorganisms. Studies have also shown that polycarbonates (particularly the aliphatic types) possess some degree of biodegradability.^[18,30]

Polymer-Degrading Microorganisms

Biodiversity and occurrence of polymer-degrading microorganisms is varied depending on the environment, such as

soil, sea, compost, activated sludge, etc. It is necessary to investigate the distribution and population of polymer-degrading microorganisms in various ecosystems. Generally, the adherence of microorganisms on the surface of plastics followed by the colonization of the exposed surface is the major mechanisms involved in the microbial degradation of plastics. The enzymatic degradation of plastics by hydrolysis is a two-step process: first, the enzyme binds to the polymer substrate then subsequently catalyzes a hydrolytic cleavage. Polymers are degraded into low molecular weight oligomers, dimers and monomers and finally mineralized to CO₂ and H₂O. Majority of the strains that are able to degrade PHB belong to different taxa such as Gram-positive and Gram-negative bacteria, *Streptomyces* and fungi. It has been reported that 39 bacterial strains of the classes Firmicutes and Proteobacteria can degrade PHB, PCL, and PBS, but not PLA.^[16,17] Only a few PLA degrading microorganisms have been isolated and identified. The population of aliphatic polymer-degrading microorganisms in different ecosystems was found to be in the following order:^[18,20]

PHB = PCL > PBS > PLA

Application of Biodegradable Plastics

Many bioplastics now have mechanical properties equivalent to that of their conventional counterparts [e.g. polypropylene (PP), polystyrene and polyethylene (PE)] and can be processed using technologies widely used in the polymer industry (e.g. compounding, film processing and molding). They have been found various in many short service life applications where biodegradability is a key advantageous feature including consumer packaging (e.g. trays, pots, films and bottles in food packaging), convenience food disposables (e.g. cutlery/tableware), bags (shopping, garden

or domestic waste), agriculture mulch films, personal-care disposals (e.g. nappies) and even golf tees. Bioplastic polymers have also been used in more durable applications such as in textiles, consumer goods, automotive parts and building and construction where the focus is on the use of renewable (bio)resources and any inherent biodegradability properties need to be suppressed or controlled by careful design. Bio-based versus biodegradable: it is important to recognize that not all bio-based polymer materials are biodegradable and vice versa. Equally, it is important to recognize that attributes like biodegradability of a given polymer need to be effectively coupled with appropriate waste management in order to capture maximum environmental benefit.^[17]

CONCLUSION

Since PET is light in weight, its feedstock are readily available and cheap, and the energy requirement for PET processing and fabrication for consumer articles is the lowest of those for the other materials, PET products for mass consumptions are affordable even to the poorest of the poor. This has resulted in the single use of PET products for mass consumption, and consequently a large volume of such products are being thrown into the garbage. It is true that disposal of PET waste, if done in the same way as followed for other materials, may create environmental problems. This is essentially because of the non-biodegradability and non-biomassimilarity of polymers. That PET is made durable according to the market demand, is the reason for their persistence in the environment causing litter problem and pollution. Thus, PET become a red herring to the environmentalists, and by their pressure, governments are forced to enact laws which are not conducive to the growth and development of polymer industry. Some of

the over-enthusiastic groups call for a ban of use of some of the mass consumed PET items. If we agree to their demand, the economically background population will suffer most because plastics have become the poor man's useful materials.^[10]

Microplastics may not only affect species at the organism-level; they also have the capacity to modify population structure. Species which were once restricted by a lack of hard substrate, such as the marine insect *H. Sericeus*, are now able to proliferate. This may be applicable to a wide range of organisms with potential impacts on ecosystem dynamics. The accumulation of microplastic debris has presented a new marine habitat where biological interactions are taking place. This habitat and its environmental impacts are still emerging areas of research. It is hoped that future work on this growing issue will contribute to the development of better methods for controlling marine litter.^[23]

But PET enjoys the advantage of easy reprocessability and recyclability. Also the waste polymers can be used to recovery energy, at least to a significant extent that was used for their production. So, waste plastics disposal should be handled carefully by adopting appropriate technologies. Waste plastics should be considered as valuable resources, particularly in countries where hydrocarbons feed stocks is scare and costly. Steps taken by industry are economy-driven, that adopted by government are legislative, and that by the public responsive. The integrated approach of waste management with the participation of industry, government and public can solve the waste disposal problem without damage to both environments and industry. Appropriate technology, legislation and waste disposal procedures should be adopted based on the socio-economic aspect of the country to solve this problem.^[10]

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