

CHAPTER II

LITERATURE SURVEY

Plastics are polymers. A polymer is an organic macromolecule (a large molecule based on carbon) comprised of several hundred or several thousand repeating segments, called mers, linked together in a chainlike form. The number of times a particular segment repeats is referred to as n , the degree of polymerization. As n becomes larger, the polymer molecule becomes longer and the molecular weight of the polymer increases. Compared to the molecules in common materials such as water or oil, the molecules that define a plastic are long ($n = 100$ to more than 1000), as can be seen in Figure 2.1.



Figure 2.1 The length of the carbon chain in plastic compared to that in water and oil.

Plastic materials are classified into two major categories: thermosetting materials and thermoplastic materials. For thermosetting materials, the crosslinking process actually is the formation of chemical bonds between the long carbon chain. The crosslinking process is irreversible. Once set, the thermosetting plastic can not revert to its prior stage. For thermoplastic materials, it is plastic material that soften upon heating and harden upon cooling. This process is reversible, just as ice hardens upon cooling but can be remolded by heating. Unlike thermosets, thermoplastics have no chemical

bonds between their long chain molecule as illustrated in Figure 2.2. In thermoplastics, it has been found that LDPE is the most widely used polymer as shown in Figure 2.3.

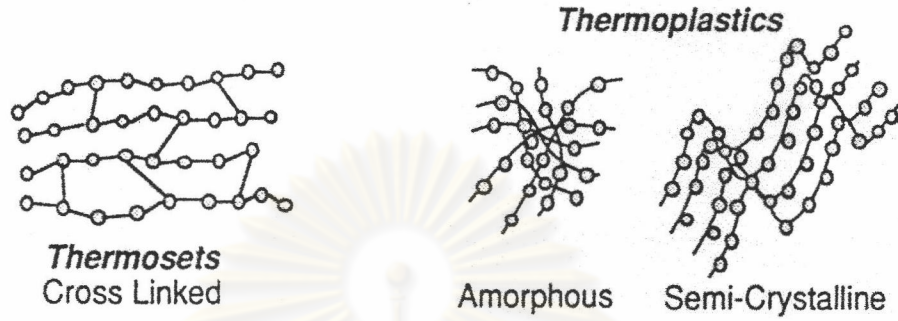


Figure 2.2 Comparison of molecular structure in thermosets and the thermoplastics.

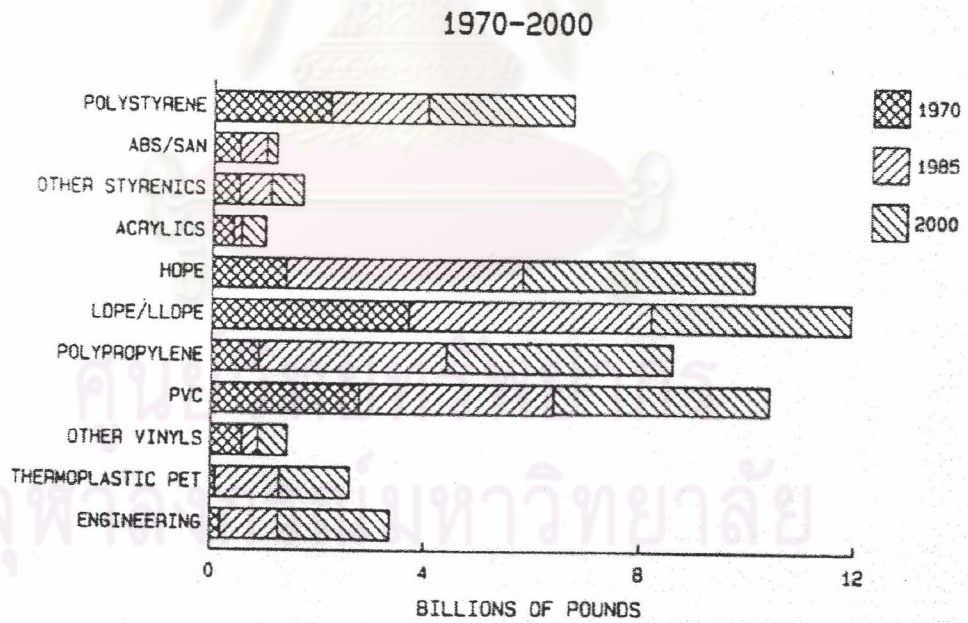


Figure 2.3 Thermoplastic growth. Source: "Plastics A.D.2000" Society of the plastics industry.

2.1 Low Density Polyethylene (LDPE) [9-12]

Polyethylene was first produced in the laboratories of Imperial Chemical Industries, Ltd. (ICI), England. The first commercial ethylene polymer was branched polyethylene, commonly designated as low-density polyethylene (LDPE). It is partially crystalline solid melting at about 115°C. It is soluble in many solvents at temperature above 100°C, but no room temperature solvents exist.

LDPE has good toughness. The electrical properties are outstanding. In thick sections, it is translucent because of its crystallinity, but high transparency is obtained in thin films. It is very chemically inert. It does not dissolve in any solvents at room temperature, but is slightly swelled by liquids such as benzene and carbon tetrachloride, which are solvents at high temperatures. It has good resistance to acids and alkalis; hence, it is often used as a container for acids.

About one-third of the LDPE produced has gone into film and sheeting uses for the last several years. Few competitive film materials have LDPE's desirable combination of low density, flexibility without plasticizer, resilience, high tear strength, moisture and chemical resistance. Over three – fourths of the LDPE film produced goes into packaging applications, including bags, pouches, wrappings for products, textile products, merchandise, frozen foods, perishable foods and many other products. Other film uses include drapes and tablecloths, extensive application in agriculture (greenhouses, ground cover, tank and pond, etc.) and construction (moisture barriers and utility covering material). Properties of LDPE are given in Table 2.1.

Table 2.1: Properties of Low-density Polyethylene [5,12]

Properties	Value
Abrasion resistance (mg/1000 cycles)	10 – 15
Brittleness (°C)	< -118
Coefficient of thermal expansion ($\times 10^{-5}$) (K^{-1})	10
Combustion product	No smoke, carbon dioxide and carbon monoxide
Decompose temperature (°C)	340 - 440
Density (g/cm^3)	0.910 – 0.925
Dielectric constant at 1 kHz	2.28
Elongation at break (%)	150 – 600
Flammability	Burn with blue flame
Glass transition temperature (°C)	-90
Hardness (shore D)	44 – 48
Heat capacity (kJ/kg/K)	1.916
Impact strength, Izod (ft/lb/in notch)	> 16
Melting temperature (°C)	115
Maximum continuous service temperature (°C)	60 – 75
Minimum continuous service temperature (°C)	- 50
Tensile modulus (MPa)	55.1 – 172
Tensile strength (MPa)	15.2 – 78.6
Transmission light	High, milky white in color
Water absorption (%)	< 0.01

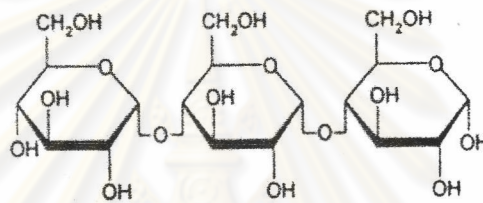
2.2 Starch [13]

During the last 30 years, considerable interest has been expressed in substituting the traditional nondegradable polymer like polyethylene (PE) by a biodegradable polymer such as starch [14], especially for short – term applications without significantly sacrificing the mechanical properties of synthetic polymers.

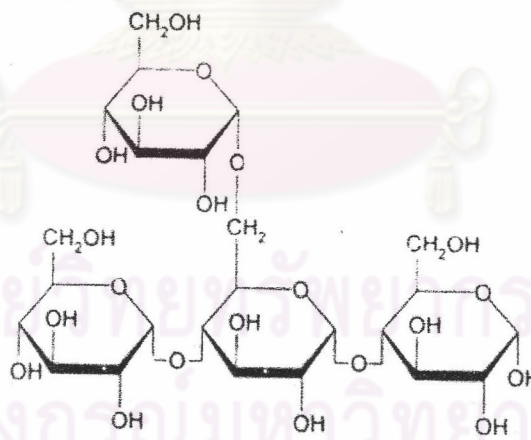
Starch is the naturally occurring polymer. It is produced by many plants and stored in the form of granules. The granules may vary in size from 2 – 150 μm , depending on source of plants. Rice starch has the smallest granules, whereas potato starch has the largest. Starch is a mixture of linear (amylose) and branch (amylopectin) polymer of α - D – glucopyranosyl units. Natural starch occurs usually as granules composed of both linear and branched starch molecules. As shown in Figure 2.4, in amylose the D-glucopyranose units are connected by (1-4) - α - glucosidic linkages, whereas in amylopectin the D-glucopyranose units are also bonded by (1-6) - α - glucosidic linkages at branch point. The linear amylose molecules of starch have a molecular weight of 0.2 – 2 million, while the branched amylopectin molecules have molecular weights as high as 100 – 400 million.

Generally, starch composes of varying amounts of amylose and amylopectin. Amylose makes up approximately one-fourth of the weight of starch. The relative amount of these two components is dictated genetically and varies for each species of starch. Starch granule contains crystalline in amylose component and amorphous in amylopectin component. From their difference in structure, amylose and amylopectin exhibit different properties. Amylose forms strong flexible films and has value as a coating agent. The branched component forms films with poor properties but finds wide usage as a thickening agent, especially in food and paper applications. The abundant hydroxyl groups on the starch molecules impart the characteristic hydrophilic properties. The starch attracts water and itself through hydrogen bonding.

Starch granules are insoluble in cold water but swell slightly due to the absorption of water. They are thermally stable in an open atmosphere to about 230°C. Above that temperature the starch molecules begin to decompose. However, starch by itself is unsuitable for use as a plastic because it is difficult to process and is extremely sensitive to humidity. Depending on the environment, physical properties such as elasticity, hardness and dimensional stability are affected. To overcome the problems caused by the poor physical properties of pure starch, it is often blended with water insoluble synthetic polymers. Advantage of starch as an additive is not only of being a cheap filler, but also of providing biodegradability properties to the final product.



Amylose



Amylopectin

Figure 2.4 Structure of amylose and amylopectin.

Starch has received maximum attention in the preparation of biodegradable plastics especially for one time used plastics [15]. This is because starch is the most abundant, degradable and low cost natural polymer. And it is also available throughout the world. Starch can be used as a natural filler in traditional plastics and particularly in polyolefins. When blended with starch, polyethylene films biodeteriorate on exposure to a soil environment. The microbial consumption of the starch component leads to increased porosity and surface area, void formation and the loss of integrity of the plastic matrix. Nominal addition level of starch in commercial films is typically 3 to 6 wt% [3].

2.3 Banana Starch

In this study banana starch was used as a filler because it is one of the most important fruits in Thailand, inexpensive and rich in starch content (14-23% on a fresh weight basis) [7].

From the literature there are 4 methods of extraction banana starch. In 1981, Kayisu et al. [16] extracted starch from raw bananas by freeze-dried for 5 days and then isolated starch by using distilled deionized water. They found that the isolated starch have protein content 0.2%, lipid 0.2% and ash 0.02%.

Afterward, in 1982, Lii and co-workers [8] extracted starch by using 0.05N sodium hydroxide (NaOH) solution and then filtered through sieve with distilled water. Prime starch was sedimented from the filtrate. It was found that green banana has 61.74% starch, while ripe banana has only 2.58% (on a dry weight basis). The isolated starch has protein 0.09%, lipid 0.11% and ash 0.057%.

More recently, in 2000, Mota et al. [7] used an aqueous solution of 4% w/v NaCl, 1% w/v ascorbic acid and 0.185% w/v ethylene-dinitrotetra acitic acid (EDTA) to extract starch from green banana. The homogenate was filtered through cheese cloth.

The slurry was centrifuged at 2°C. The precipitate was washed twice with a cold aqueous solution of 4%w/v NaCl followed by acetone. At the same time, Perez et al. [17] used a sodium sulfite solution to isolate starch from banana. The homogenate was sieved and centrifuged. After that, the white starch sediments were dried at 40°C for 2 days.

In conclusion, green banana has starch content much more than ripe bananas. As graphically shown in Figure 2.5, after 10 days starch converts into sugar when it ripens. Therefore, green banana was used in this study.

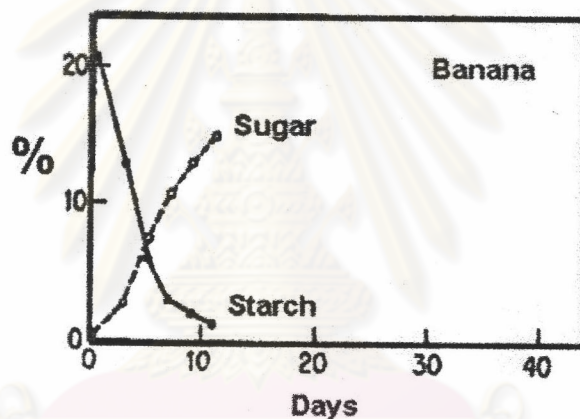


Figure 2.5 Starch to sugar conversion [18].

2.4 Biodegradable Polymer

As the applications of plastics increase with time, especially in the packaging material, a logical consequence is the increased use of environmentally friendly degradable polymers as one of the many means to reduce the problems of polymer waste management.

Many research attempts have been focused on the use of natural biopolymers such as starch, cellulose, lignin, chitin and chitosan, which are also fully biodegradable [6]. They are produced from renewable and natural sources. Degradable plastics are very important as part of the solution to the waste management problem, especially polyolefins, the most extensively used in disposal packaging materials. Polyolefins has interest for many years due to its nonbiodegradability, causing many environmental problems associated with plastic disposal after their usage. Therefore, a lot of researches have been conducted to improve biodegradability of synthetic polymers including polyolefins by adding natural biopolymers such as starch into these polymers to reduce amount of plastic waste. Figure 2.6 presents cycle of starch-based polymer in solution to the polymer waste problem.

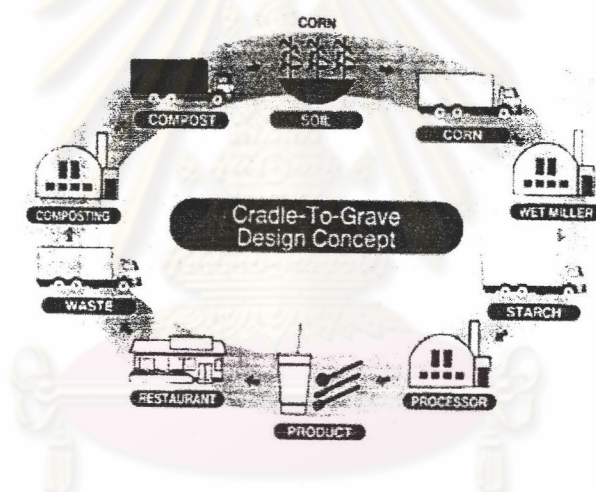


Figure 2.6 Cycle of polymer/starch blends to solve the problems of polymer waste [13].

In the early 1970's Griffin [19] had the idea to increase biodegradability of polymers by incorporating a cheap biodegradable additive. In his work, he mixed granular corn starch with LDPE and found that the degradation of the LDPE/starch blend film in a compost environment was accelerated by the addition of starch. Peroxides were generated and consequently, autoxidation was enhanced. Thus, a purely chemical effect of the biotic surroundings, even with no enzymatic actions, could enhance the degradative autoxidation of the polymers.

In 1987, Maddever et al. [20] reported work carried out with Ecostar, a starch based LDPE masterbatch manufactured by St. Lawrence of Canada. The research findings showed that the effect of starch on starch/LDPE film properties was similar to that found from the addition of other fillers at similar levels. When starch contents were varied from 0 to 9%, the tear strength increased in the machine direction. The yield strength remained constant within a narrow range while the strength at break decreased in both the machine and transverse directions. The ultimate elongation was reduced and the impact strength dropped sharply at 9% loading level.

7 years later, George et al. [21] examined the effect of poly (ethylene-co-vinyl alcohol) (EVOH) concentration on the processibility and physical properties of corn starch plasticized with glycerine and water. They found that the injection moldability increased with increasing EVOH concentration as evidenced by decreasing injection pressure required to fill the mold. The higher injection pressures exhibited by the high amylose starch blends suggesting that it is more difficult to process the linear amylose than the branched amylopectin. Blends with the high amylose corn exhibited higher injection pressures than the blends containing waxy maize or native corn starch. The addition of EVOH increased the ductility of the pure plasticized starches. The high amylose corn blend exhibiting higher elongation at low EVOH concentration than waxy maize and native corn starch.

Later in 1995, Bhattacharya et al. [22] reported that the addition of starch to ethylene – propylene – g – maleic anhydride copolymer (EPMA) caused a significant reduction in the percentage elongation of the blends but little reduction in the tensile strength. For starch/styrene maleic anhydride copolymer (SMA) blends the tensile strength dropped to between 60 and 80% of SMA. Higher humidity increased the elongation of starch/EPMA blends, but for starch/SMA blends, caused a significant decrease in the tensile strength.

In the last few years an effort was undertaken for the production of biodegradable synthetic polymers by Simmons et al. [23]. They studied blends of native

corn starch and EVOH. These blends were conditioned to various moisture contents. They found that the elongation at break decreased with volume fraction of starch, but increased with moisture content. This result indicates that starch is brittle phase at low moisture content. The trend in the tensile strength with moisture is opposite to that in elongation at break.

Recently, the results of Ioannis and his co-worker [24] appeared to be in the same trend as other previous works. In their work, blends of LDPE and rice or potato starch were extruded in the presence of varying amounts of water. The blends were then studied in terms of their mechanical properties, gas/water permeability and biodegradability before and after storage. They reported that high starch contents promoted brittleness and resulted in lower tensile strength and modulus. Gas permeability and water vapour transmission rate increased with starch content. The biodegradability rate of the blends was enhanced when the starch exceeded 10% w/w. Degradability of sample resulted in the decreasing of mechanical strength, tensile and flexural modulus and percentage elongation.

2.5 Compatibilizer

In blends of starch with synthetic polymers such as PE, PP and PS, the difference in polar character of starch and polymers leads to poor adhesion between the two phases, resulting in a reduction in mechanical properties. One way to improve the compatibility between starch and polyolefin is to use a compatibilizer.

A compatibilizer may be a polymer, or more commonly a copolymer, of polarity intermediate between the component polymers of the blend. Or it may be a block or graft copolymer with segments of each of the component polymers. It is well known that the role of compatibilizer is to reduce the interfacial energy and hence increase the interfacial adhesion between polymers. In doing so, the compatibilizer will react with the

hydroxyl group of starch and form a hydrogen bond or covalent bond with synthetic polymer.

The most frequently used compatibilizer for starch/polyolefin blends is ethylene – co – acrylic acid copolymer (EAA). This is because, as can be seen from Figure 2.7, EAA contains both PE segment and acrylic acid unit, which can form hydrogen bond between the carboxylic groups of acrylic acid and hydroxyl groups of starch.

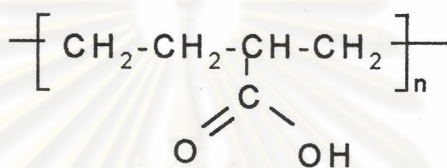


Figure 2.7 Chemical structure of EAA.

Although EAA has some disadvantage that its cost is 4 times more expensive than starch and it retards the biodegradation, the use of EAA to promote the compatibility in starch-based plastics has been studied extensively [2].

In 1979, Otey et al. [25] discovered that compounds of polyethylene, ethylene – acrylic acid copolymer (EAA) and starch could be formed into films that were flexible, water-resistant, heat stable and biodegradable. Several methods such as casting, simple extruding, or milling the starch – EAA compositions were used to produce the films. The processes were relatively slow and expensive in comparison with the more conventional extrusion blowing technique.

Later, in 1994, Willet [26] studied the mechanical properties of composites of granular starch and LDPE as a function of starch volume fraction, granular size and presence of compatibilizer. The addition of ethylene-co-acrylic acid copolymer (EAA), as a compatibilizer, did not significantly affect the elongation and tensile strength, but

the modulus. A large increase in modulus was observed as the starch content increased, but decreased as the EAA content increased. As the particle size decreased, the yield strength, ultimate tensile strength and modulus increased at constant starch content. In contrast, particle size had no effect on the elongation. In addition, the results showed that the potato starch composites had lower tensile strength than the corn starch composites.

As mentioned earlier, although EAA has been used widely, its disadvantage has lead the researchers to find the new compatibilizer for starch/polyolefin system. Recently, Prinos et. al. [2] studied a series of LDPE blends with plasticized starch and granular starch. Ethylene/vinyl acetate copolymer (EVA) was used as a compatibilizer. Chemical structure of EVA is shown in Figure 2.8. They found that elongation at break was satisfactory even for blends containing high amounts of starch. The blends with granular starch had lower tensile strength than the blends with plasticized starch. The compatibilizer in the blends increased the tensile strength compared with the uncompatibilized blends. The addition of compatibilizer had a small negative effect on the tensile strength of the blends since the tensile strength decreased slightly with increasing amount of EVA. EVA copolymer has a small exhibiting effect on the biodegradation rate.

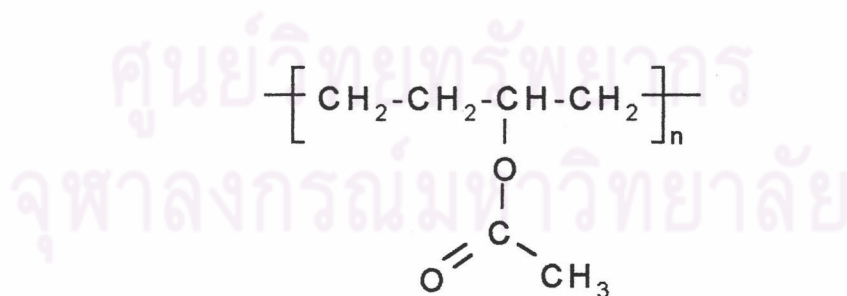


Figure 2.8 Chemical structure of EVA.

2.6 General Aspect of Polymer Degradation [27,28]

Polymer degradation is used to denote changes in physical properties caused by chemical reaction. It is a harmful process, which is to be avoided or prevented. Degradation may happen during every phase of a polymer life, i.e., during its synthesis, processing and use. Depending on polymerization conditions, during polymer synthesis depolymerization may take place. Depolymerization is the inverse of polymerization. During process, the material is subjected to very high thermal and mechanical stress. Degradation mode depends on application of products but generally are multi-action modes.

There are four mechanisms by which plastic materials degrade in environments. The degradation mechanisms are as follows:

1. Microbial degradation, where fungi and bacteria – secreting enzymes degrade the plastic under aerobic or anaerobic conditions. The rate of degradation is sensitive to microbial population, moisture, temperature and oxygen in the environment.
2. Macroorganism degradation, where invertebrates and insects such as crickets, slug and snails consume the plastic as food. Macroorganism degradation occurs in three stages involving :
 - (1) Mastication (chewing); results in considerable deterioration of the physical and chemical structure of the plastic.
 - (2) Digestion; in the macroorganism removes the digestible components by enzymes and mechanochemical action.
 - (3) Exocorporeal digestion; involves the fate of nondigested fecal material and orally contacted pieces of plastics.
3. Photodegradation, where absorption of UV radiation from the sun leads to the decomposition of plastic molecules. Photodegradation has the potential of

facilitating biodegradation by reducing the molecular weight and introducing oxygen groups on the chain, which also facilitates chemical degradation.

4. Chemical degradation, where chemical additives such as oxidants and peroxides promote reactions which lead to the deterioration of the plastic molecular structure.

Other factors such as mechanical action, wind and rain can also deteriorate the polymer. The extent to which polymers degrade is dependent upon the environment surrounding the disposed polymer and type of polymer. It is well documented that hydrocarbon polymers such as PE and PS, of M_n more than 100000, do not biodegrade within a period of time (10 years) [28]. The size of the individual polymer chains, the crystallinity and the chemical nature are some of the factors which influence the degradation of polymers.

2.7 Biodegradation [29]

Biodegradation is the natural process. It can only occur within the biosphere and microorganisms play a central role in the biodegradation process. For plastics, biodegradable plastics are polymeric materials, which are changed into lower molecular weight compounds. The change in the chemical structure of biodegradable plastics under specific environmental conditions results in a loss of some properties including physical and mechanical properties. The biodegradation processes are usually followed by monitoring the changes in these properties using standard test methods appropriate to the plastic. Today's plastics are designed with little consideration for their ultimate disposability. This has resulted in mounting worldwide concerns over the environmental consequences of such materials. Because they were entered to the waste stream after their uses especially in single use and disposal plastic applications.

Polymer waste management requires sound complementary practices of conservation, recycling, incineration and biodegradation. Since biodegradation is potentially the most environmentally friendly of all these practices, there is activity in the area of biodegradable polymers as packaging materials.

Generally, starch removal does occur when the starch-based films are exposed to microbial. The first mechanism of degradation is the production of enzyme amylase by microbial. Then the enzyme amylase diffuse into pores for degrade the starch. Finally, the soluble digestion products are diffused back to the microbial, as shown in Figure 2.9.

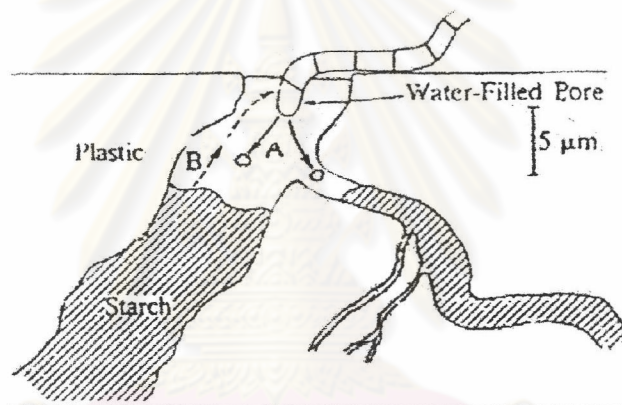


Figure 2.9 Mechanism of microbial decay of plastic/starch blends.

A : Diffusion of amylase to starch

B : Diffusion of digestion products to fungus

Generally, there are several ways to test the biodegradability of plastics. Five methods for testing biodegradability are highlighted as following:

(1) Petri Dish Screen

This method involves placing the test material (2.5cm x 2.5cm) on the surface of a mineral salts agar in a petri dish. The test material and agar surface are sprayed or painted with a standardised mixed inoculum of known fungi or bacterial and kept at a constant temperature for between 21 and 28 days. The test material is then examined for the amount of growth on its surface and rating given, as shown in Table 2.2.

Table 2.2: Rating Scheme Based on Visual Assessment Used for Assessing Fungal Resistance of Plastics

Visual Assessment	Rating	Evaluation
No growth apparent even under the microscope	0	The material is not a nutritive medium for microorganisms
Growth invisible or hardly visible to the naked eye but clearly visible under the microscope	1	The material contains nutritive substances
Slight growth covering less than 25% of the specimen surface	2	The material is not resistant to fungal attack and contains nutritive substances
Growth covering more than 25% of the specimen surface	3	As for rating 2

The more growth on the surface, the more likely is the material intrinsically able to support growth and thus the more likelihood that it will fail in service.

Weight loss and mechanical tests can be carried out on the test material after exposure provided that the correct types of specimens (e.g. dumbbells) have been used in the test.

(2) Environmental Chamber Method

Environmental chambers employ high humidity (> 90%) situations to encourage microbial growth. Test materials are hung in the chamber, sprayed with a standard mixed inoculum of known fungi in the absence of additional nutrients and incubated for 28 to 56 days at constant temperature. A visual assessment is subsequently made and a rating given based on the amount of growth on the material, as shown in Table 2.2. This test is particularly stringent and was designed to simulate the effects of high humidity conditions on electronic components and electrical equipment. Growth of fungi across a printed circuit board can result in a gross systems failure in a computer system or military equipment.

(3) Soil Burial Tests

The material is buried in soil beds prepared in the laboratory. The soil beds containing the samples are incubated at a constant temperature for between 28 days and 12 months. The soil beds are normally conditioned for up to 4 weeks prior to use and may be supplemented with organic fertilizer to encourage an active microbial. The microbial activity is tested using a cotton textile strip, which should lose 90% of its tensile strength within 10 days of exposure to the soil. The moisture content is normally set at 20-30%. Samples are removed for assessment of changes in their properties such as weight loss, mechanical properties, or a microscopic (SEM) examination to assess surface damage. However, the soil burial tests are that a 3 to 6 months test is sufficient to demonstrate the environmental resistance of polymer materials.

(4) Specific Microorganism

Biodegradation is an event which takes place through the action of enzymes associated with living organisms (bacteria, fungi, etc.). Generally, microorganisms produce enzyme involving in the chemical mode of degradation and attack natural polymers. The attack is specific with respect to both the enzyme and biopolymer couple. All enzymes are protein, even small changes in temperature or pH can result in changes in the enzyme activity. The accessibility of a polymer to be degradatively attacked by living organisms has no direct reaction to its origin and not all biopolymers are truly biodegradable. This test method is also appropriate for the evaluation of degradable plastics that have undergone specific chemical, thermal, or photo degradation, or combination.

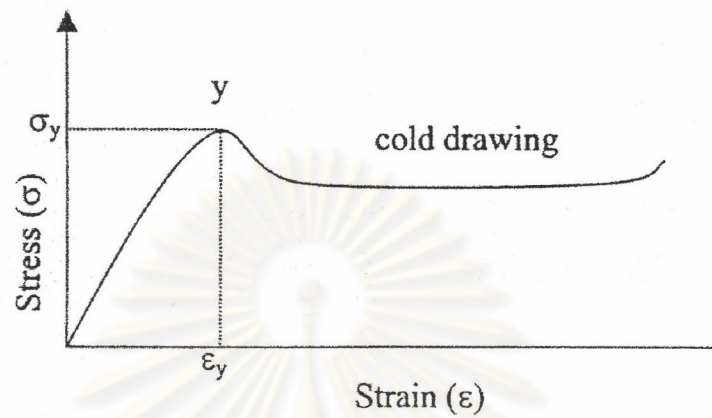
(5) Activated Sludge Waste Water Treatment

This method is the simulation studies range from laboratory designed equipment, which replicates aerobic sewage treatment and anaerobic sludge digestion, through the exposure trials where material is submerged in activated sludge environment. Exposure trials require that the samples be securely held on some form of racking for aqueous environments. The racks, normally made of stainless steel, are submerged in the test situation and samples periodically removed. This test method is designed to be applicable to all plastic materials that are not inhibitory to the bacterial present in the activated sludge.

2.8 Tensile Properties [12]

The tensile properties are often the most important properties because end – use applications involve some degree of mechanical loading. The material selection for a variety of applications is quite often based on tensile properties such as tensile

strength, modulus and elongation. One such typical stress – strain diagram is illustrated in Figure 2.10.



where σ_y = Stress at yield
 ϵ_y = Strain at yield
 y = Yield point

Figure 2.10 Stress – strain curve.

Tensile stress is the tensile force per unit area of the original cross – section within gauge length. Strain is the change in length per unit original length of the measured gauge length of the test specimen. It is expressed as a dimensionless ratio. The tensile modulus is the ratio of the tensile stress to strain. For such materials the slope of tangent to the stress – strain curve at a low strain is usually taken as the elastic modulus.

The point in the stress – strain curve where the stress (or load) begins to decrease with increasing strain (or extension) is referred to as the yield point. After the yield point, there is a sudden decrease in the cross sectional dimension (width and thickness) of the specimen. This is termed “necking”, as seen in Figure 2.11. The

specimen exhibits non – recoverable, plastic deformation. Thus, for molded products this point would normally represent the limit of its usefulness.

The maximum tensile stress sustained by a specimen during a tension test is its tensile strength. When the maximum stress occurs at the yield point, this stress is designated tensile strength at yield. The percent elongation at yield is the extension at yield divided by the original gauge length of the specimen multiplied by 100.



Figure 2.11 Necking of a tensile specimen.

The tensile test provides insight into the stress-strain behavior of a material under uniaxial loading and makes it possible to distinguish between brittle and ductile materials under a given set of test conditions. Tensile values are strongly influenced by temperature, loading rate and moisture level. Figure 2.12 shows stress-strain curves for a polymer at four different temperatures. The tests were each conducted to failure at a single temperature and the arrow indicates the direction of increasing temperature.

At a temperature well below the glass transition temperature (curve A), a brittle fracture occurs. The stress rises linearly to the break point with increasing strain and

rupture occurs at low strain. At a high temperature (curve D), the polymer is rubber-like and stress rises to the breaking point with a sigmoidal relationship to the strain. Rupture occurs at a very high strain.

In an intermediate temperature range below the glass transition (curve B), the stress-strain relationship resembles that of a ductile metal, showing a stress maximum, i.e. a yield point before rupture occurs. At a slightly higher temperature but still below the glass transition (curve C), the remarkable phenomenon of necking and cold drawing is observed. The curve again shows yield point and a subsequent decrease in the stress. However, with a further increase in the applied strain, the stress falls to a constant level at which a neck forms. Eventually the stress begins to rise again and rupture occurs.

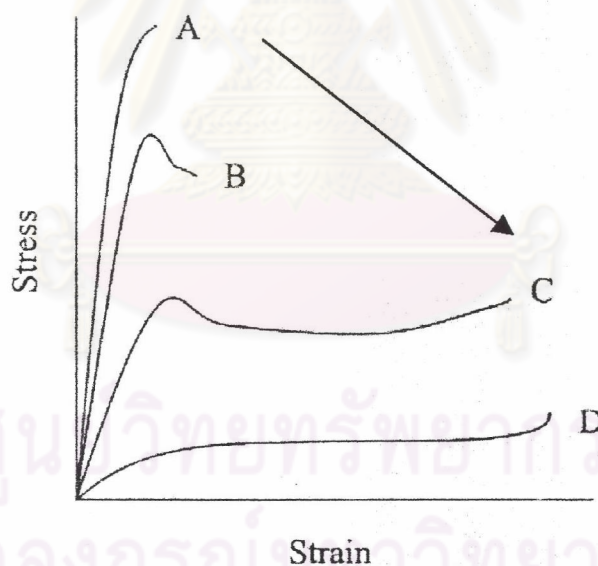


Figure 2.12 Variation of stress-strain results with temperature.

2.9 Processing [5,30]

The materials most often used in packaging are paper, wood, glass, steel and plastic. Plastic competes with all of these other materials in some aspect of packaging. The advantages of plastics include low weight, durable, ease of forming and economy.

Packaging is a major application for the plastics industry, accounting for about one-fourth of all plastics used in the United States. Low-density polyethylene and high-density polyethylene combined account for the largest function of plastic used in packaging, as seen in Figure 2.13.

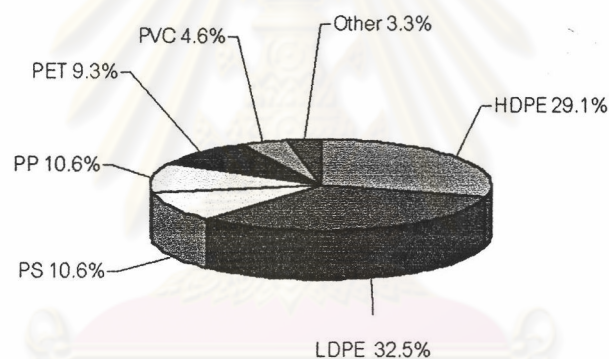


Figure 2.13 Proportion of different plastics used in packaging [5].

In nearly all applications for packaging plastics, the first step is to convert the solid plastic, usually in pellet form, into a melt. This process may involve mixing in additive such as color concentrates, blending resins together and incorporating regrind. The final melt must be uniform in concentration.

Generally, there are several methods for processing the plastic film such as blown film, calendering, chill roll cast film, two roll mill and extruder. In this section,

however, only 2 techniques namely twin screw extruder and chill roll cast film which involve in manufacturing plastic films will be shortly described as follow:

(1) Twin Screw Extruder

In the past two decades, twin screw extruders have developed into the most popular continuous mixing devices. In general, they can be divided into counter – rotating and co– rotating types. As the names indicate, the difference is in whether the two screws rotate in the same or in opposite directions, as can be seen in Figure 2.14 and 2.15, respectively.

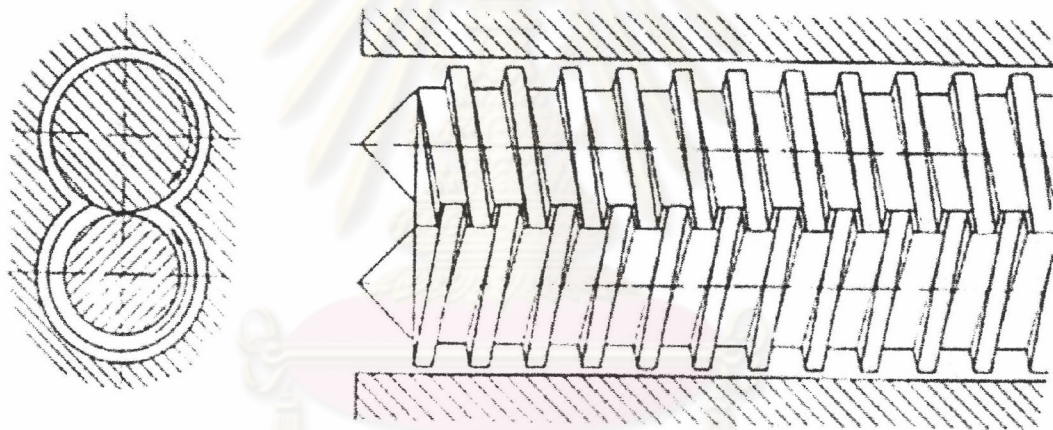


Figure 2.14 Counter – rotating twin screw extruder.

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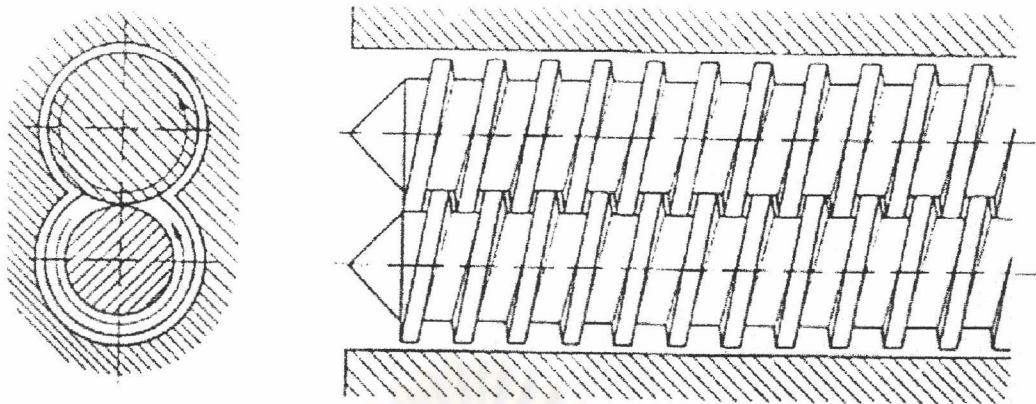


Figure 2.15 Co – rotating twin screw extruder.

The plastic pellets are fed into the barrel through a hopper at one end and then conveyed by the screw to the other end of the barrel. The depth of the channels in the screw decreases with distance from the hopper, building up pressure on the plastic. External heating as well as internal heating from friction between the plastic and the screw cause the plastic to soften and melt. A simplified twin screw extruder diagram is shown in Figure 2.16.

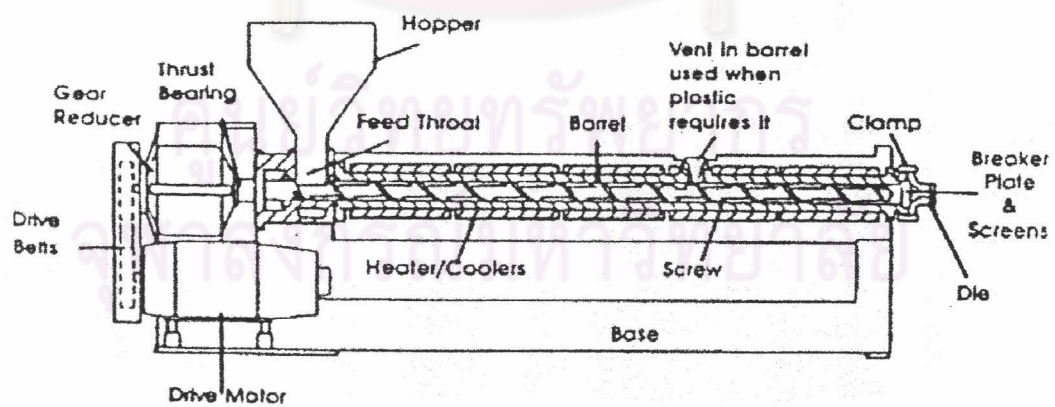


Figure 2.16 Twin screw extruder.

The first, next to the feed hopper, is the feed section. Its function is to get the plastic into the extruder at a relatively even rate. Generally, this section is maintained at a relatively cool temperature, to avoid blockage in the feed channel. Next comes the compression section, in which most of the melting occurs and pressure is built up. The transition between the feed section and the compression can be abrupt or gradual. Finally, next to the extruder outlet, is the metering section. Its purpose is to assure a uniform flow of material out of the extruder. At the end of the barrel, the melted plastic leaves the extruder through a die, which has been designed to impart the desired shape to the stream of melted plastic. This may be the final shape for the plastic, or it simply may be the beginning of further processing. For the production of film, the plastic pellets from twin screw extruder are fed to the hopper chill roll cast for film forming.

(2) Chill Roll Cast Film

Most commonly, cast film and sheet produced by extrusion of the melt onto chilled rollers. In a cast film extrusion process, a thin film is extruded through a slit onto a chilled, highly polished, turning roll where it is quenched from one side. The roll is highly polished to give good surface characteristics to the resulting film. The film is then sent to a second roller for cooling of the other side. Generally, the film travels in an S-pattern around at least two chill rolls, sometime more, before the film is cool enough to wind. Finally, the film passes through a system of rollers and is wound onto a roll. The film dimensions are controlled primarily by the extrusion rate and take-off speed. A typical film casting process is depicted in Figure 2.17.

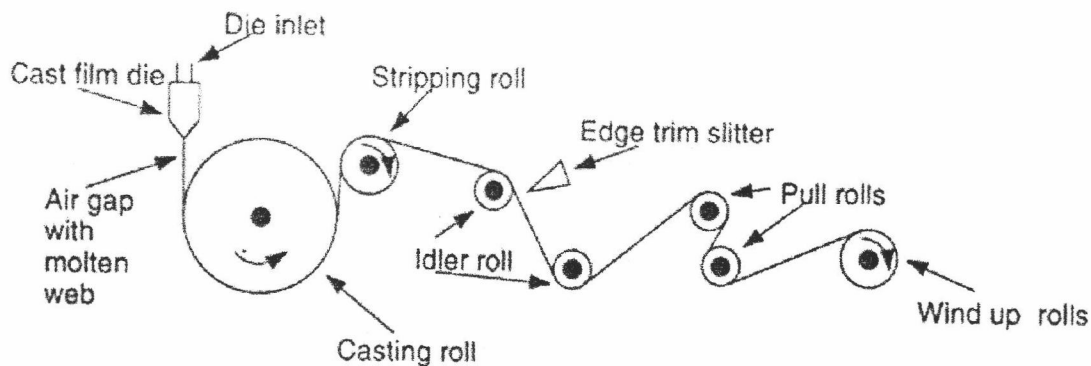


Figure 2.17 Chill roll cast film.

Cast film properties can be modified by orientation, or stretching of the film under conditions causing some molecular realignment in the direction of the stretch, which persists when the force is removed. Orientation tends to increase crystallinity, barrier properties and strength in the stretched direction, while decreasing strength in direction perpendicular to the orientation direction.

If the cast film is not stretched significantly in machine direction (the direction of travel through the production equipment), it is relatively unoriented and has fairly balanced mechanical properties in the machine and cross directions. If the takeoff speed is significantly higher than the rate of extrusion, the plastic is stretched and uniaxially oriented. The stretching can occur at the initial contact with the chill roll, but is more commonly done after the first chill roll. If the plastic is also stretched in the cross machine direction, it is biaxially oriented. Biaxially orientation can be accomplished in either a single step or, as occurs more commonly, in two consecutive steps, as shown in Figure 2.18 and 2.19, respectively. The resulting film is balanced if the orientation is equal in the two directions, or unbalanced if it is more highly oriented in one direction than the other.

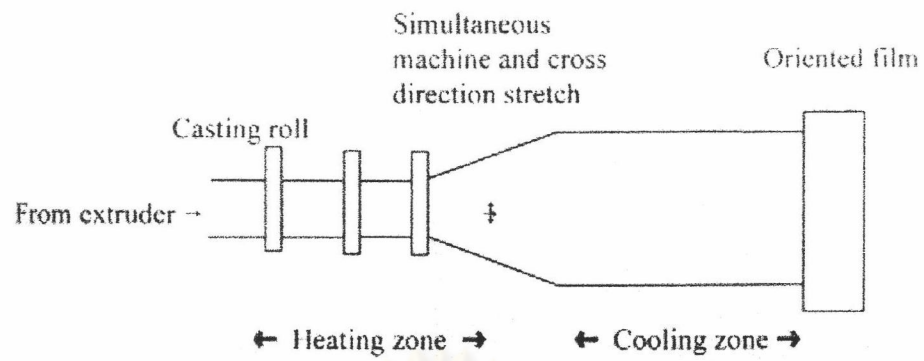


Figure 2.18 One-step orientation of cast film.

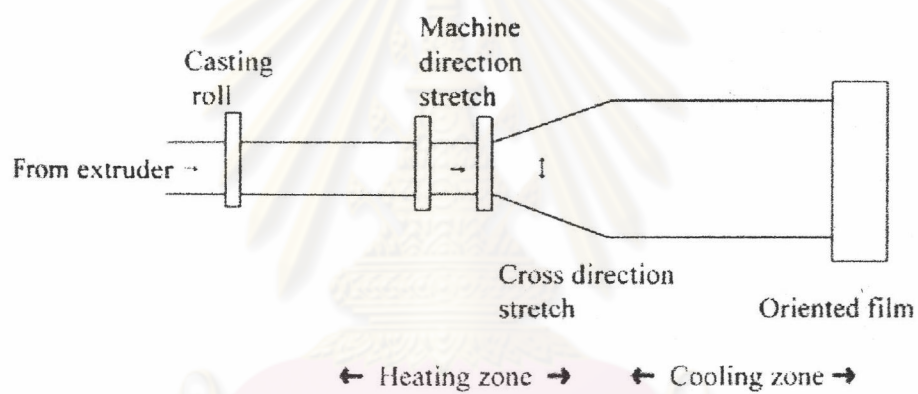


Figure 2.19 Two-step orientation of cast film.

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