CHARACTERIZE THE MECHANICAL PROPERTIES OF SELECTED TYPE OF COASTAL PLASTIC WASTE

MOHD HAFIZ BIN ISMAIL

BACHELOR OF CHEMICAL ENGINEERING

UNIVERSITY MALAYSIA PAHANG

CHARACTERIZE THE MECHANICAL PROPERTIES OF SELECTED TYPE OF COASTAL PLASTIC WASTE

MOHD HAFIZ BIN ISMAIL

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Bachelor of Chemical Engineering

Faculty of Chemical and Natural Resources Engineering
UNIVERSITI MALAYSIA PAHANG

JANUARY 2012

SUPERVISOR'S DECLARATION

"I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Bachelor of Chemical Engineering."

Signature: ....

Supervisor: EN MOHD SHAIFUL ZAIDI BIN MAT DESA

Position: LECTURER

Date: 31 JANUARY 2012

STUDENT'S DECLARATION

I hereby declare this thesis entitled "CHARACTERIZE THE MECHANICAL PROPERTIES OF SELECTED TYPE OF COASTAL PLASTIC WASTE" is my own except for quotations and summaries which have been duly acknowledge. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature: ....

Name: MOHD HAFIZ BIN ISMAIL

ID Number: KA 08047

Date: 31 JANUARY 2012

ACKNOWLEDGMENTS

First of all, praise to The Almighty for its guidance, I can finish my undergraduate research project with the very excellent even through there are some problems occurred.

I also like to express a special thanks to my beloved family for their strong support and infinity blessed for me to finish my Bachelor Degree.

Not to forget to my supervisor, En Mohd Shaiful Zaidi Bin Mat Desa for his support and sincere guidance and to my academic advisor, Madam Hamidah binti Abdullah who always taking care of my education and give me advices on academic and life after that. Once again thank you so much to all of you.

Lastly, thank you so much to all my lecturers and my fellow friends for their support and knowledge given to me.

ABSTRACT

Human are heavily dependent on the sea for economic and sources of high-protein food. In the past 10 years, coastal plastic pollution has extremely increased and this circumstance may affect human healthiness, difficulties to marine activities, and decreasing of quality of seawater. Not only plastic is made from a non-renewable resource, but it is generally a non-biodegradable material which made biodegradation process is very slow. Due to that recycling of coastal plastic waste is one of possible measures to be taken to tackle this issue. However, because of long exposure to the seawater and direct sunlight, the mechanical properties of coastal plastic waste would differ from the commercial plastic. The objectives of this study are to characterize mechanical properties of coastal plastic waste and compare the mechanical properties of coastal plastic waste with the commercial plastic and to analyse the differences of mechanical properties between coastal plastic waste and commercial plastic. Four types of common plastic; Polypropylene (PP), Polyethylene (PE), Polyethylene Terephthalate (PET), and Polyvinyl Chloride (PVC) are used as samples. These samples are collected, cleaned, and sorted according to type of plastics before being shredded. Then samples is melted and formed into a continuous profile via extruder and palletized into pallet-size samples. Next, samples are moulded into desired shape in accordance with American Society for Testing and Materials (ASTM) standard and tested utilizing Universal Testing Machine (UTM). From all results obtained, the mechanical properties for all type of coastal plastic wastes differ from mechanical properties of commercial plastic. This is due to the presence of salt in seawater and also direct sunlight towards the plastic waste which lead to degradation. It is recommended that other type of plastics should be used as samples and other mechanical properties should be studied in order to differentiate properties of coastal plastic waste and commercial plastic precisely.

ABSTRAK

Laut merupakan sumber utama protein dan ekonomi kepada manusia sejagat. Sejak 10 tahun yang lalu, pencemaran plastik di laut meningkat dengan mendadak dan perkara ini boleh menjejaskan kesihatan manusia, kesukaran kepada aktiviti perikanan, dan pengurangan kualiti sumber air. Bukan hanya plastik diperbuat daripada sumber yang tidak boleh diperbaharui, tetapi secara umumnya plastik merupakan bahan yang tidak terbiodegradasi atau melalui proses biodegradasi dengan sangat perlahan. Oeh itu, proses kitar semula merupakan salah satu pilihan untuk menangani isu ini. Walaubagaimanapun, disebabkan pendedahan yang lama kepada pancaran cahaya matahari dan air laut secara terus, sifat-sifat mekanik sisa plastik dari pantai ini akan berbeza berbanding plastik komersial. Objektif kajian ini adalah untuk mencirikan sifat-sifat mekanik sisa plastik dari pantai, membandingkan sifat-sifat tersebut dengan plastik komersial dan menganalisis perbezaan sifat-sifat mekanik antara sisa plastik dari pantai dengan plastik komersial. Empat jenis plastik yang biasa dijumpai dipantai; Polypropylene (PP), Polyethylene (PE), Polyethylene Terephthalate (PET), dan polyvinyl Chloride (PVC) digunakan sebagai sampel. Semua sampel dikutip, dibersihkan, dan disusun mengikut jenis sebelum dihancurkan. Kemudian sampel akan dipanaskan sehingga cair dan dibentuk menjadi pellet. Kemudian, pellet tersebut akan dibentuk mengikut piawaian yang ditentukan oleh American Society for Testing and Materials (ASTM) antarabangsa dan diuji menggunakan Universal testing Machine (UTM). Berdasarkan semua keputusan yang diperolehi, sifat-sifat mekanik untuk semua jenis sisa plastik pantai menunjukkan perbezaan daripada sifat-sifat mekanik plastik komersial. Hal ini disebabkan oleh kehadiran garam dalam air laut dan juga cahaya matahari secara langsung ke arah sisa plastik ini yang membawa kepada proses degradasi dan perubahan sifat-sifat mekanik. Dengan ini, disarankan bahawa jenis plastik yang lain harus digunakan sebagai sampel dan sifat-sifat mekanik yang lain perlu dikaji untuk membezakan sifat-sifat pantai sisa plastik dan plastik komersial dengan lebih tepat.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

%	Percentage
Σ	Summation
$\bar{X}$	Average value
R*	Free redical
H	Hydrogen
O_2	Oxygen

LIST OF ABBREVIATIONS

PP	Polypropylene
PE	Polyethylene
LDPE	Low-density Polyethylene
HDPE	High-density Polyethylene
PVC	Polyvinyl Chloride
PET	Polyethylene Terephthalate
O&G	Oil and Gas
TSS	Total suspended solids
ASTM	American Society for Testing and Materials
UTM	Universal Testing Machine
DOE	Department of the Environment Malaysia
MPa	Mega Pascal
GPa	Giga Pascal

CHAPTER 1

INTRODUCTION

1.1. BACKGROUND OF STUDY

Malaysia’s region is geographically unique and located at South East-Asia. The country is known by two lands mass; Peninsular Malaysia region and Borneo Island, which separated by South China Sea. Almost 90% of Malaysians live within 100km from seaside and approximately 70% of them stay along coastline areas. Most of them are resident of Kelantan, Terengganu, Sabah and Sarawak which are really depending on the sea for their economic sources. In general, marine is contributing almost 20% of protein for human need.

However, from past 10 years, marine pollution has extremely increased and this circumstance can threaten life of the next generation. This pollution may cause destructive consequences toward human health, complications to marine activities, and also dwindling of the quality of seawater for countless applications. 80% of the marine pollution is caused by land-based activities such as factory wastes that flow directly into the ocean, rubbish that dropped into the street washes then end up in the ocean and also the tourists and visitors themselves leave rubbish on the beach. On top of that, long-lasting plastics generally make up about 60% of rubbish and are the worst killers in the ocean. From previous research, almost 100,000 of marine mammals including dugong, dolphins, whales and turtles are killed by plastic rubbish every single year around the world.

Due to the plastic is a non-biodegradable matter, all those coastal plastic wastes should be recycled to save the earth. However, the process of recycle cannot be performed unless the mechanical properties of coastal plastic wastes are understood. This is due to the mechanical properties of coastal plastic waste which differ from commercial plastic due to presence of salt contained in the seawater and also degradation caused by direct sunlight to the plastic. Once the mechanical properties of coastal plastic wastes were found, further processes can be performed to recycle the plastic wastes.

Table 1.1: Emission of organic water pollutants

	Emissions of organic water pollutants				Industry shares of emissions of organic water pollutants							
	kilograms per day		kilograms per day per worker		Primary metals %	Paper and pulp %	Chemicals %	Food and beverages %	Stone, ceramics, and glass %	Textiles %	Wood %	Other %
	1980	1993	1980	1993	1993	1993	1993	1993	1993	1993	1993	1993
Hungary	201,888	151,311	0.15	0.18	9.9	7.6	8.1	54.9	0.2	10.8	1.8	6.8
India	1,457,474	1,441,293	0.21	0.20	15.6	8.1	7.3	50.9	0.2	12.9	0.3	4.8
Indonesia	214,010	537,142	0.22	0.19	..	7.8	10.4	58.9	0.2	15.4	4.8	2.6
Iran, Islamic Rep.	72,334	101,763	0.15	0.16	21.7	7.8	7.9	38.2	0.6	17.6	0.8	5.5
Iraq	31,805	17,882	0.18	0.15	..	15.4	16.6	43.2	0.8	18.3	0.4	5.2
Ireland	43,544	33,417	0.19	0.17	1.6	17.3	9.6	54.5	0.2	7.5	1.5	7.7
Israel	39,113	50,030	0.15	0.16	4.1	19.3	8.4	44.3	0.2	12.3	2.1	9.3
Italy	442,712	353,906	0.13	0.13	17.0	16.1	10.5	25.8	0.3	16.1	2.1	12.1
Jamaica	11,123	17,752	0.25	0.27	0.7	7.3	4.6	75.4	0.1	10.0	1.1	0.8
Japan	1,456,016	1,548,021	0.14	0.14	9.9	22.0	8.8	36.5	0.2	7.9	1.9	12.8
Jordan	4,146	11,166	0.17	0.17	4.1	15.3	15.9	49.8	0.7	7.6	3.4	3.3
Kazakhstan	..	..	..	..	..	..	..	..	..	..	..	..
Kenya	26,150	44,065	0.19	0.23	..	11.5	5.6	68.6	0.1	9.1	1.9	3.2
Korea, Dem. Rep.	..	..	..	..	..	..	..	..	..	..	..	..
Korea, Rep.	281,900	358,610	0.14	0.13	12.8	15.4	11.2	25.8	0.3	20.8	1.5	12.2
Kuwait	6,921	9,052	0.16	0.16	2.5	16.1	11.4	47.9	0.4	12.4	3.7	5.5
Kyrgyz Republic	..	25,426	..	0.19	14.2	3.0	1.1	53.5	0.5	26.1	1.5	..
Lao PDR	..	..	..	..	..	..	..	..	..	..	..	..
Latvia	..	42,866	..	0.15	2.4	7.9	5.3	57.2	0.3	14.5	3.8	8.5
Lebanon	13,137	..	0.24	..	..	..	..	..	..	..	..	..
Lesotho	190	87	0.11	0.09	..	69.5	27.6	..	2.0	..	..	0.9
Libya	3,532	..	0.21	..	..	..	..	..	..	..	..	..
Lithuania	..	..	..	..	..	..	..	..	..	..	..	..
Macedonia, FYR	..	29,054	..	0.17	16.6	8.4	6.0	37.7	0.1	24.5	2.0	4.7
Madagascar	9,196	..	0.23	..	..	..	..	..	..	..	..	..
Malawi	12,224	..	0.32	..	..	..	..	..	..	..	..	..
Malaysia	77,215	136,055	0.15	0.12	6.8	14.3	15.2	31.8	0.2	11.1	7.6	13.1
Mali	1,774	..	0.30	..	..	..	..	..	..	..	..	..

Source: World Development Indicator (1998)

1.2. PROBLEM STATEMENT

Mechanical properties of many materials especially plastics can vary depending on nature of surrounding. As plastics waste which had exposed to sea environment, it will tend to have some differences in term of mechanical properties compared to standard commercial plastics. Due to almost all types of plastic are made of non-renewable resources and environmental concern, all the coastal plastic wastes should be recycled. However, in order to recycle all those coastal plastic wastes and reproduce new commercial plastics, the mechanical properties of coastal plastic wastes should be investigated so that the recycling process can be done effectively.

1.3. OBJECTIVE OF RESEARCH

The main point of view of this study is to transform the unusable coastal plastic waste into valuable new recycled product by studying the mechanical properties of coastal plastic waste. As regards to this point of view, there are three objectives of this research which are:

i. To characterize mechanical properties of coastal plastic waste,
ii. To compare the mechanical properties of coastal plastic waste with the commercial plastic.
iii. To analyse the differences of mechanical properties between coastal plastic waste and commercial plastic.

1.4. RATIONALE AND SIGNIFICANCE OF STUDY

Marine pollution especially caused by plastic matters is getting higher. Plastics are non-biodegradable materials and it will tend to have special mechanical properties once it submerged in seawater for a period of time. The mechanical properties of coastal plastic wastes should be different from commercial plastic thus causing inconvenience in carrying out the process of recycling. Therefore, this study will be conducted in order to characterize the mechanical properties of coastal plastic wastes. Once the data of mechanical properties of coastal plastic wastes can be obtained, further processes for recycling plastic waste can be performed very well.

1.5. RESEARCH QUESTION

i. Are the mechanical properties of coastal plastic waste can be determined?
ii. Are there any differences in term of mechanical properties between coastal plastic waste and also commercial plastic?

1.6. SCOPE OF RESEARCH

In order to achieve the objectives, these following scopes have been identify and to applied:

i. The sample which is plastic waste will be collected at beaches around Kuantan, Pahang.
ii. Selected type of plastic will be used to characterize the coastal plastic wastes which are Polypropylene (PP), Poly Vinyl Chloride (PVC), Polyethylene (PE), and Polyethylene Terephthalate (PET),
iii. The only mechanical properties that being studied for selected plastic types are Modulus of Elasticity, Tensile Strength and also Percentage of Elongation.

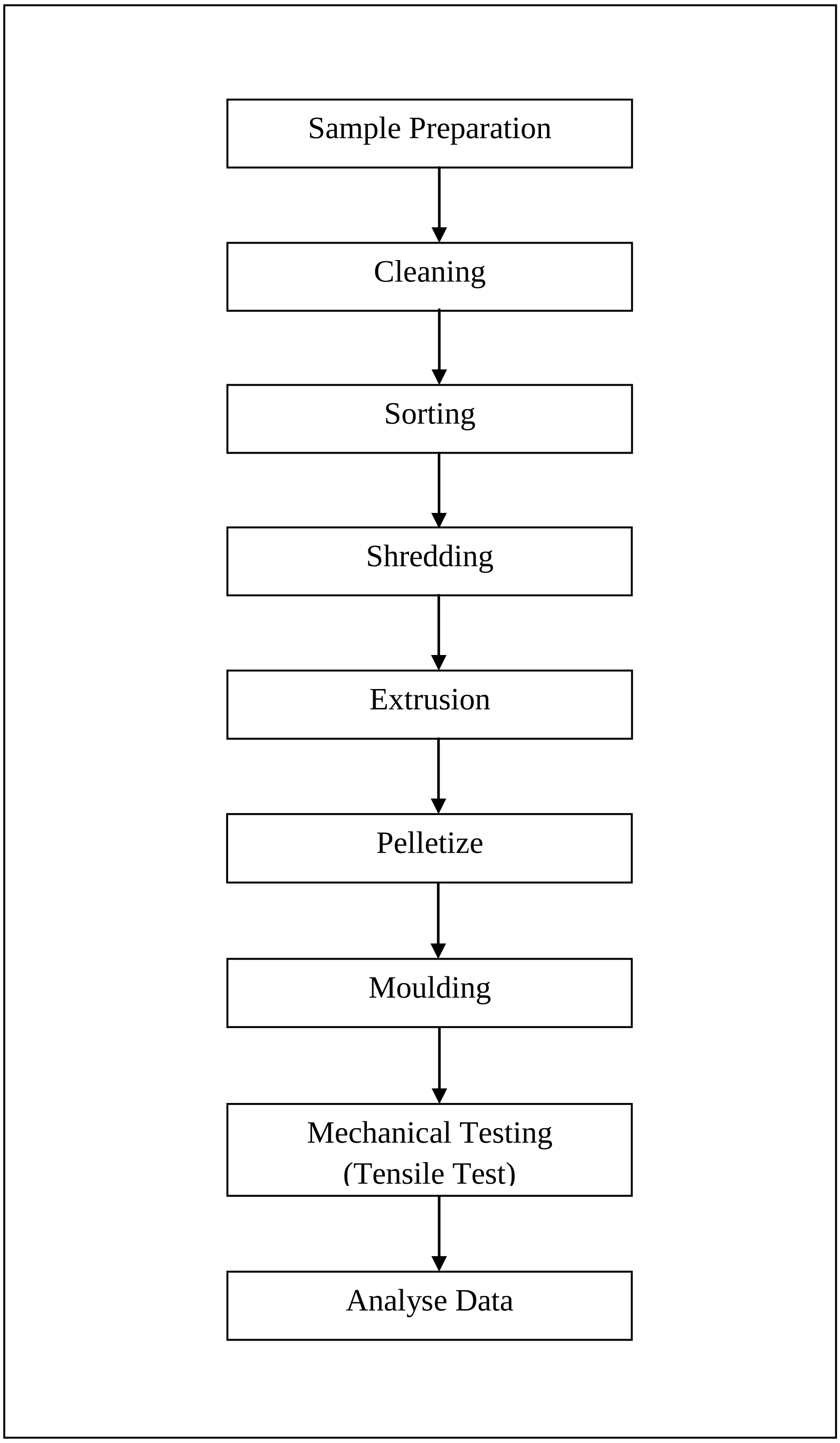

Figure 1.1: Experimental workflow

CHAPTER 2

LITERATURE REVIEW

2.1. MARINE POLLUTION

Marine pollution can be defined as the introduction by man, directly, or indirectly, of substances or energy to the marine environment. This pollution may result in harmful effects towards human health, difficulties to marine activities, and also deterioration of the quality of seawater for various uses. From previous study, 80% of the marine pollution is caused by land-based sources. Domestic wastes and sewage, including solid and liquid wastes are major pollutants of coastal waste. Some of the sources come from rubbish that dropped in the street washes into drains ends up in the ocean and factory wastes that flow directly into the ocean without any systematic waste management. Marine pollution also caused by humans' activities on the oceans for examples kitchen boat waste, discharged and by accidently lost fishing nets and floats (Henry, 2011).

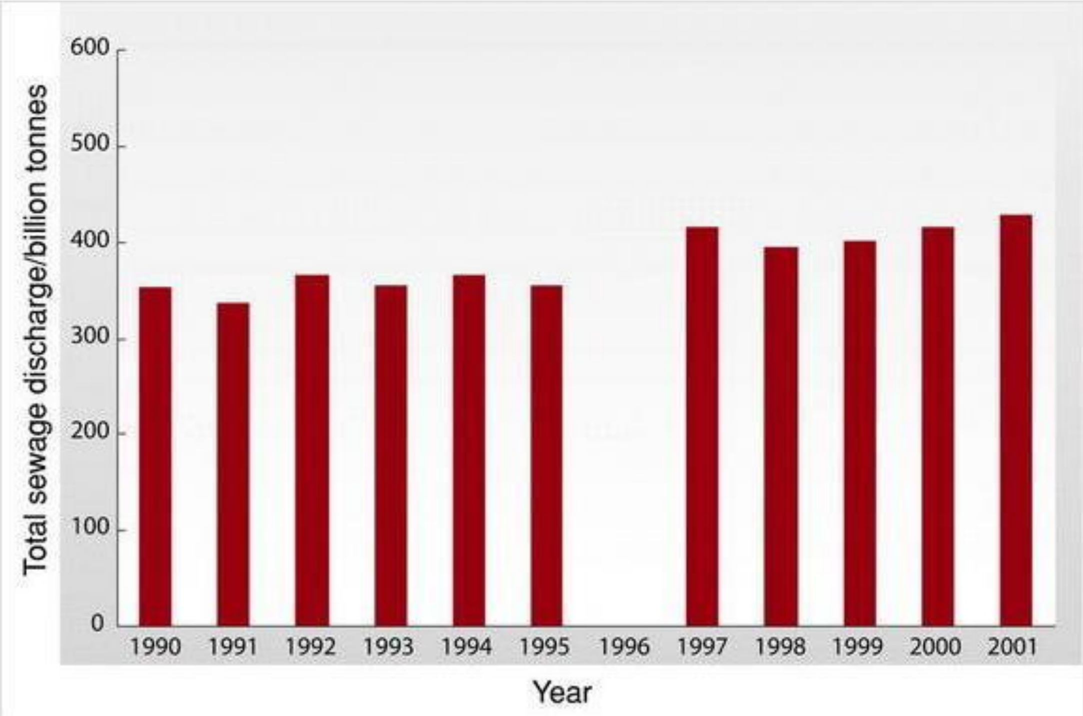

Figure 2.1: Ocean pollution from land-based activities

Source: http://www.csa.com

According to Department of The Environment Malaysia (DOE), from 1999 to 2004, they found that marine pollution had beyond the standard sea water quality recommended, especially for such parameters of oil and grease (O&G), total suspended solid (TSS), and also coliform bacteria (E.coli). Oil spills from oil tankers or during ship cleaning process have contributed to the increasing of O&G parameter. Meanwhile, most of the parameter of TSS and E.Coli contaminants caused by development activities in coastal areas such as construction, industrial activities, and also livestock activities. According to Cho and Kadaruddin (1997), construction of tourist attraction centres in the coastal environment has negative impacts towards marine pollution and the potential for beach erosion.

Table 2.1: The average concentration of O&G, TSS, E.Coli and Heavy Metal in sea water, Malaysia for 1999 – 2004

Pollutant	Standard Sea Water Quality Recommended	1999	2000	2001	2002	2003	2004
O&G	0 mg/l	2.46	1.00	0.85	0.94	0.95	1.20
TSS	50 mg/l	108	108	174	118	153	139
E.Coli	100MPN/100ml	41643	79693	39739	48594	24127	14276
Copper	0.1 mg/l	0.036	0.031	0.042	0.049	0.065	0.056
Mercury	0.001 mg/l	0.001	0.002	0.001	0.001	0.003	0.001
Lead	0.1 mg/l	0.015	0.045	0.042	0.042	0.134	0.162
Cadmium	0.1 mg/l	0.002	0.003	0.004	0.007	0.019	0.029
Arsenic, mg/l			0.1	0.002	0.003	0.017	0.002
Chromium, mg/l			0.5	0.034	0.009	0.036	0.039

Source: Department of the Environment Malaysia (2005)

Table 2.2: PVC waste per end-use category, aggregated, in Kilo tonne

Waste Type	Year			
	1998	2000	2005	2010
Agricultural	28	29	28	25
Building	1026	1070	1366	1660
Packaging	692	644	585	589
Industry	89	98	115	141
Automotive	180	195	208	216
TOTAL	2015	2036	2302	2606

Source: Tukker *et al* (1999)

2.2 PLASTIC

Plastic also known as polymer is a gigantic molecule which composed of repeating units called monomer. The term monomer refers to small molecules or atoms that have chemical bonding to form polymer (Callister, 2008). This means polymer is large molecules consist of repeating unit of monomer bind together via interatomic bond. For example, polybutadiene is a common polymer consist of monomer called 1,3-butadiene.

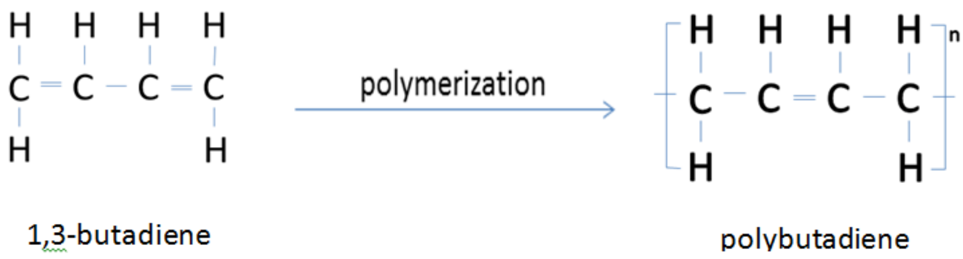

Figure 2.2: Polymerization of 1,3-butadiene

There are two subdivisions of plastics which are thermoplastic and also thermosetting. Thermoplastic is a linear polymer (single chain of monomer) and also branched polymer (linear polymer with side chain) and it softens when heated. While thermosetting is a cross-linked polymer (two or more linear polymer joined by side chain) and it hardens when heated.

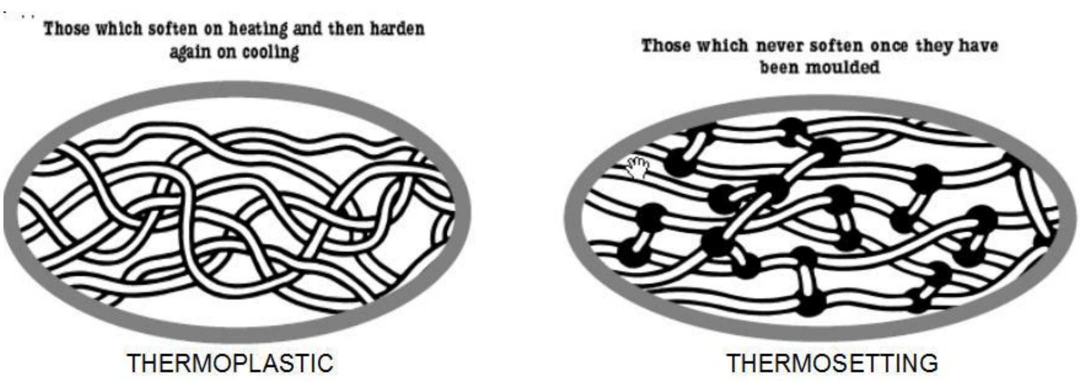

Figure 2.3: Differences between thermoplastic and thermosetting

Source: http://tecnoelpalo.wikispaces.com

There are millions of types of polymer that exist in the whole world. However, only four types of polymer will be analyzed to make comparison in term of mechanical properties. They are Polyethylene (PE), Polypropylene (PP), Polyethylene Terephthalate (PET) and also Polyvinyl Chloride (PVC).

2.2.1. Polyethylene (PE)

Polyethylene is a polymer with an ethylene monomer as repeating units. Polyethylene is one of the thermoplastic polymers. There are two types of Polyethylene; High Density Polyethylene (HDPE) and Low Density Polyethylene (LDPE). LDPE regularly used in plastic bags, cling film, and flexible containers. Meanwhile, HDPE usually used in production of automotive fuel tank bottles, toys, and also piping system due to it much more stronger and more rigid, as well as being more dense and higher-melting rather than LDPE.

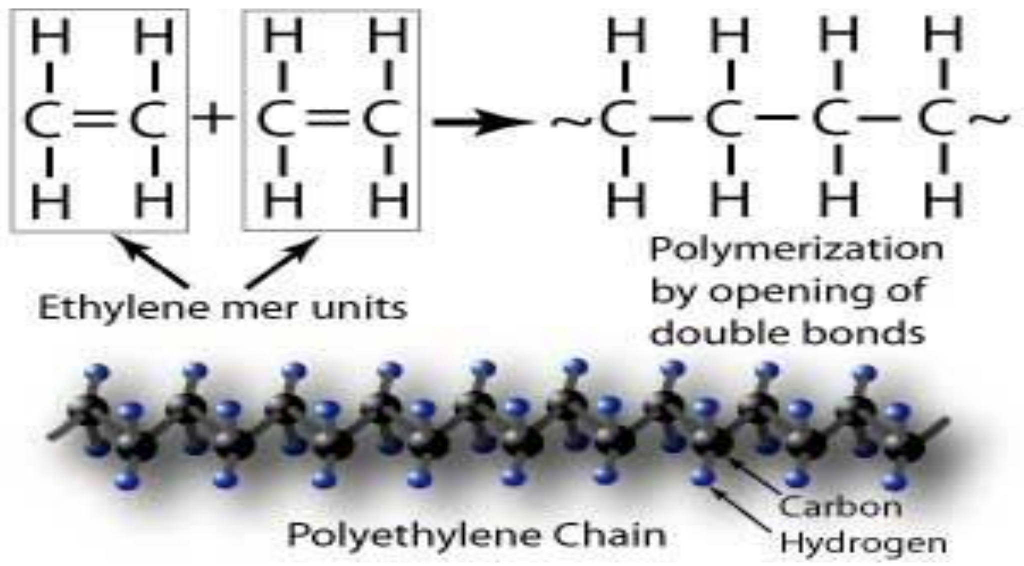

Figure 2.4: Polymerization of Polyethylene

Source: http://www.ndt-ed.org

There are some of mechanical properties of commercial Polyethylene as shown in Table 2.3.

Table 2.3: Mechanical Properties of Polyethylene

	Value	Unit
Modulus of Elasticity		GPa
• LDPE	0.282	
• HDPE	1.08	
Poisson's Ratio		
• LDPE	0.4	
• HDPE	0.46	
Yield Strength		MPa
• LDPE	14.5	
• HDPE	26.2	
Tensile Strength		MPa
• LDPE	31.4	
• HDPE	31.0	
Percent Elongation		%
• LDPE	100	
• HDPE	10	

Source: Callister (2008)

2.2.2. Polypropylene (PP)

Polypropylene is a thermoplastic polymer with propylene monomer as repeating units. Propylene is used in wide variety of application, including food containers, battery cases, automotive parts, bottle crates and also fibres. Polypropylene exists in two types which are homopolymer and also co-polymer grade. Monopolymer is a polymer with just one repating monomer while copolymer is made of different type of monomers. Copolymer polypropylene is less strong and less stiffness rather than homopolymer polypropylene. However, copolymer polypropylene is tougher and more durable than homopolymer polypropylene.

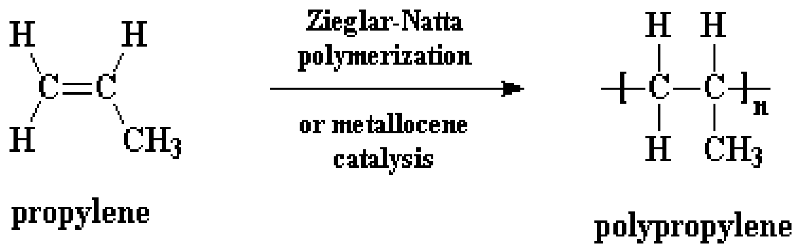

Figure 2.5: Polymerization of Polypropylene

Source: http://www.pslc.ws

Commercial Polypropylene has its own mechanical properties as follows:

Table 2.4: Mechanical Properties of Polypropylene

	Value	Unit
Modulus of Elasticity	1.55	GPa
Poisson's Ratio	0.40	
Yield Strength	37.2	MPa
Tensile Strength	41.1	MPa
Percent Elongation	100	%

Source: Callister (2008)

2.2.3. Polyethylene Terephthalate (PET)

Polyethylene Terephthalate is a polymer consists of polymerized units of the monomer called ethylene terephthalate, with repeating unit of $C_{10}H_8O_4$. Polyethylene terephthalate is a thermoplastic polymer, which is in solid structure at room temperature. However, it can flow if it is heated above its glass transition temperature and become solid again when cooled. Polystyrene is widely used in production of dairy product containers, cups, plates, packaging trays, and also moulding compound.

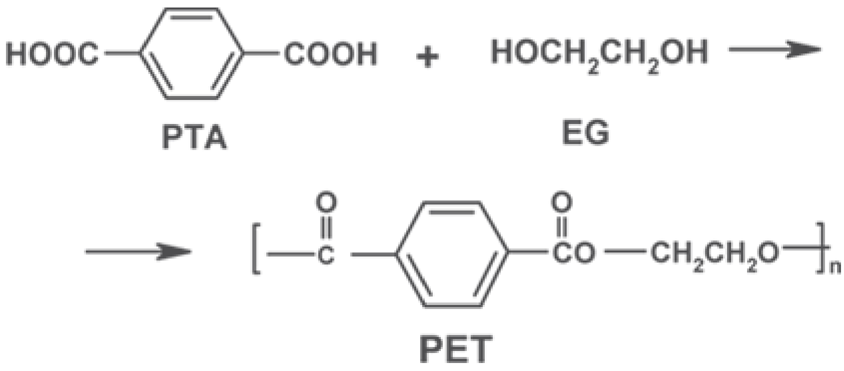

Figure 2.6: Polymerization of Polyethylene Terephthalate

Source: http://www.pslc.ws

There are some of mechanical properties of commercial Polyethylene Terephthalate as follows:

Table 2.5: Mechanical Properties of Polyethylene Terephthalate

	Value	Unit
Modulus of Elasticity	2.80	GPa
Poisson's Ratio	0.44	
Tensile Strength	80.00	MPa
Percent Elongation	60.00	%

Source: Callister (2008)

2.2.4. Polyvinyl Chloride (PVC)

Polyvinyl Chloride is a common polymer constructed of repeating unit of ethenyls monomer but one of the hydrogen branches is replaced by chloride group. Polyvinyl Chloride is one of thermoplastic polymer which commonly used in manufacture of flooring, window frames, packaging films, cable insulation, medical products and also credits cards.

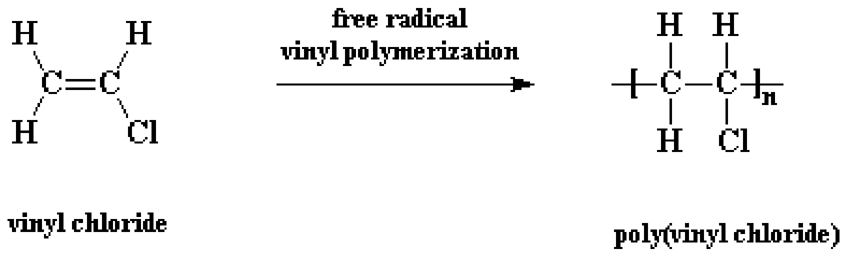

Figure 2.7: Polymerization of Polyvinyl Chloride

Source; http://www.pslc.ws

The mechanical properties of Polyvinyl Chloride are as follow:

Table 2.6: Mechanical Properties of Polyvinyl Chloride

	Value	Unit
Modulus of Elasticity	2.41-4.14	GPa
Poisson’s Ratio	0.38	
Yield Strength	40.7-44.8	MPa
Tensile Strength	40.7-51.7	MPa
Percent Elongation	40-80	%

Source: Callister (2008)

2.3. RECYCLING OF PLASTIC

Recycling of plastics can make a contribution to reducing the waste problem, which may result in economical as well as environmental benefits. However, there are a number of factors that are complicating recycling of plastics which are collection of plastic waste, separation of plastic waste, cleaning of plastic waste, and pollution of plastic waste. Major problem occurring in most industries are the large variety of plastic types. Due to the large diversity of plastic types, it is complicated to separate of different sorts, which is really crucial for effective recycling. In addition, plastic may consist of a number of secondary substances and additives, some of which are very polluting. These additives can also slow down or denied the use of certain recovery option.

Another problem occurs is pollution problem caused by mixtures of different kind of material especially in combination with PVC that are almost impossible to recycle. For example, when there are very small amount of PVC remains in the recyclates of PET, the PVC will decompose faster than PET. At this decomposition process, acids are released which may damage the structure of PET which cause the PET to discolour and become more brittle.

2.3.1. Process of Recycling

The quality of the final products derived from waste plastics will be better if all contaminants, such as non-plastics and dirt, are removed first before start reprocessing, and if the degree of moisture is reduced to lowest value possible. It is also essential that the different types of plastics are segregated as carefully as possible. Thus the waste plastic should be sorted, washed and dried first before size reduction. The several steps of recycling process are as inFigure 2.8..

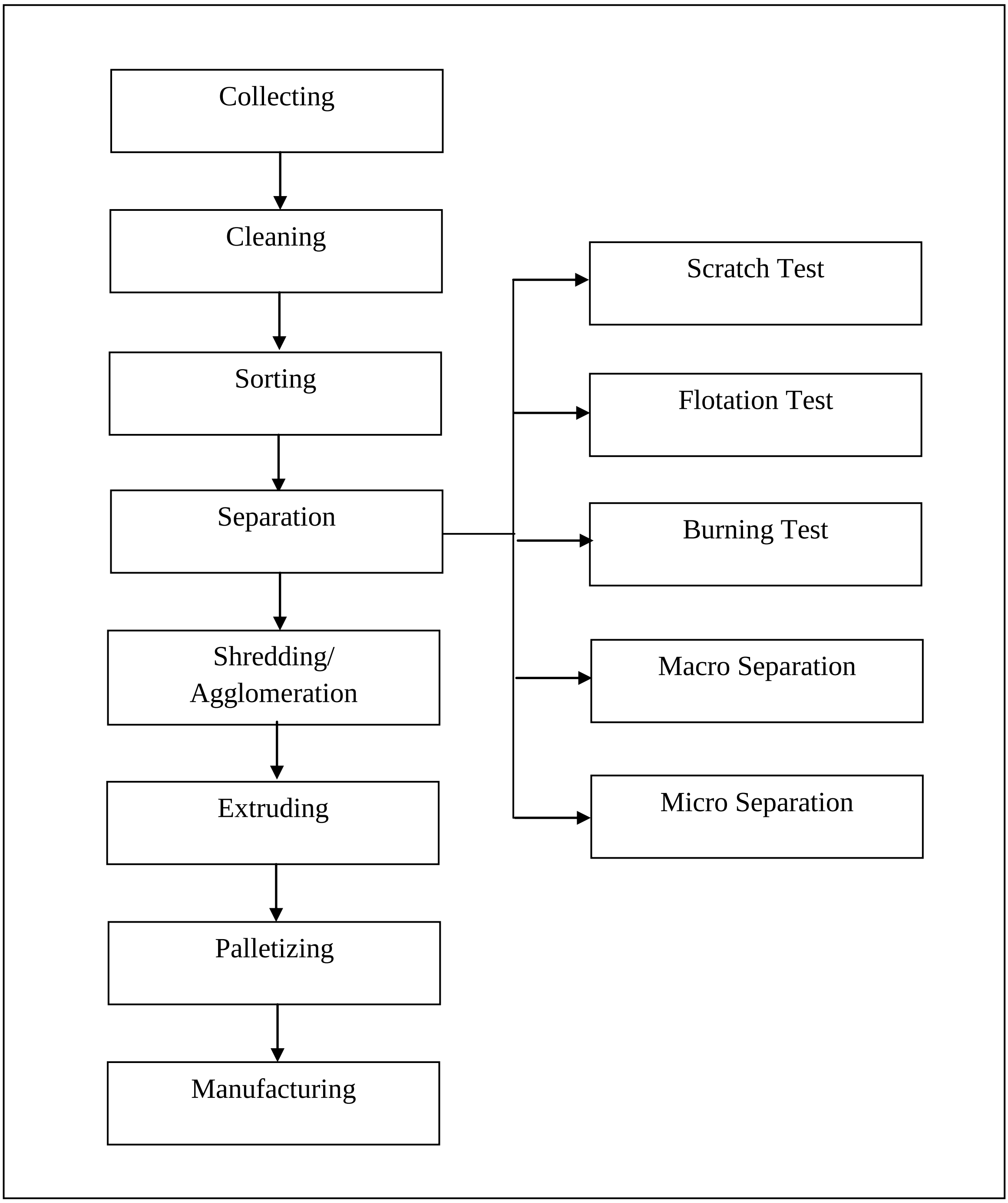

Figure 2.8: Process of plastic recycling

Source: Plastic Recycling Fact Sheet (2009)

2.3.2. RECYCLED PLASTIC

The best way to limit coastal plastic waste that created day after day and to prevent the extinction of most of marine life is through recycling. Plastics are increasingly used in routine life, thus recycling is more important ever than to reduce waste. Classifying the type of plastic is important due to each type of plastic is recycled in different way. Thus, the Plastic Identification Code is stamped on all plastics product to categorize the type of resin used. The Plastic Identification Code for each type of plastic are as follow:

Table 2.7: Identification Code for each type of resin used

Identification Code	Type of Polymer	Uses
1	Polyethylene Terephthalate (PET)	Soft drinks, fruit juice bottle
2	High-density Polyethylene (HDPE)	Milk bottles, shampoo container
3	Polyvinyl Chloride (PVC)	Cordial, juice, squeeze bottle
4	Low-Density Polyethylene (LDPE)	Garbage bags, bins
5	Polypropylene (PP)	Ice cream container, take-away food container, lunch boxes
6	Polystyrene (PS)	Yoghurt containers, plastic cutlery, foam hot drink cups
7	All other plastic including acrylic and nylon	Safety shield, plastic lumber application

Source: Plastic Recycling Fact Sheet (2009)

CHAPTER 3

METHODOLOGY

3.1. CHEMICAL AND MATERIAL USED

In this research, three selected types of plastic are going to be examined. They are Polypropylene (PP), Polyethylene (PE) and Polyvinyl Chloride (PVC). These three types of plastic were elected because they are classified within the group of thermoplastic; linear and branched polymers that become soften when heated. Only the group of thermoplastic can be recycled but not all thermoplastic are recyclable

3.2. EQUIPMENT

In order to obtain the data, only particular equipment should be used. The equipment that are going to be use are extruder, palletizer, moulder, and also universal testing machine (UTM).

3.2.1 Extruder

Extruder is a device used for melting, pressuring, and homogenising plastics. This equipment will change the shape of raw material into simpler design before further process can be done. In this experiment, coastal plastic waste will be put into extruder and change the plastic’s original shape to continuous fine cylinder shape.

Figure 3.1: Extruder

3.2.2. Pelletizer

Pelletizer is equipment used for cutting the product of extruder into pellet form. Pellet form is needed when further process of moulding take place.

Figure 3.2: Pelletizer

3.2.3. Moulder

Moulder is a machine used to design and produce desired shape of plastic. In this research, moulder is extremely needed to produce desired shape of samples before performing some mechanical tests. There are two types of moulder which are injection and compression moulder. However, injection moulder will be used due to it create very fine surface of specimen and it is available at the Mechanical Laboratory, UMP. The specimen geometry to be moulded is width = 2.90mm, gauge length = 28.04mm, and thickness = 3.94mm.

3.2.4. Universal Testing Machine

Universal testing machine is a machine that can perform almost all mechanical testing for plastics. A complete universal testing machine which also known as universal tester consists of load frame, load cell, cross head, output device, conditioning and also test fixtures. This machine is a perfect device to test such mechanical properties of coastal plastic waste due to it is computerized data generated which means the data collected are very precise and accurate. The function of some basic components is shown as in Table 3.1.

Table 3.1: Function of some basic components of Universal Testing Machine

Basic Component	Function
Load Frame	Support the machine.
Load Cell	Load transducer; a place where the load is measured.
Crosshead	A movable part that may move in constant speed. It can be change manually by pressing up or down button on the controller.
Output device	Record all results.

Figure 3.3: Universal testing Machine

3.3. EXPERIMENTAL WORKFLOW

The experimental workflow for the process of characterizing the mechanical properties of coastal plastic waste is shown as in Figure 3.4.

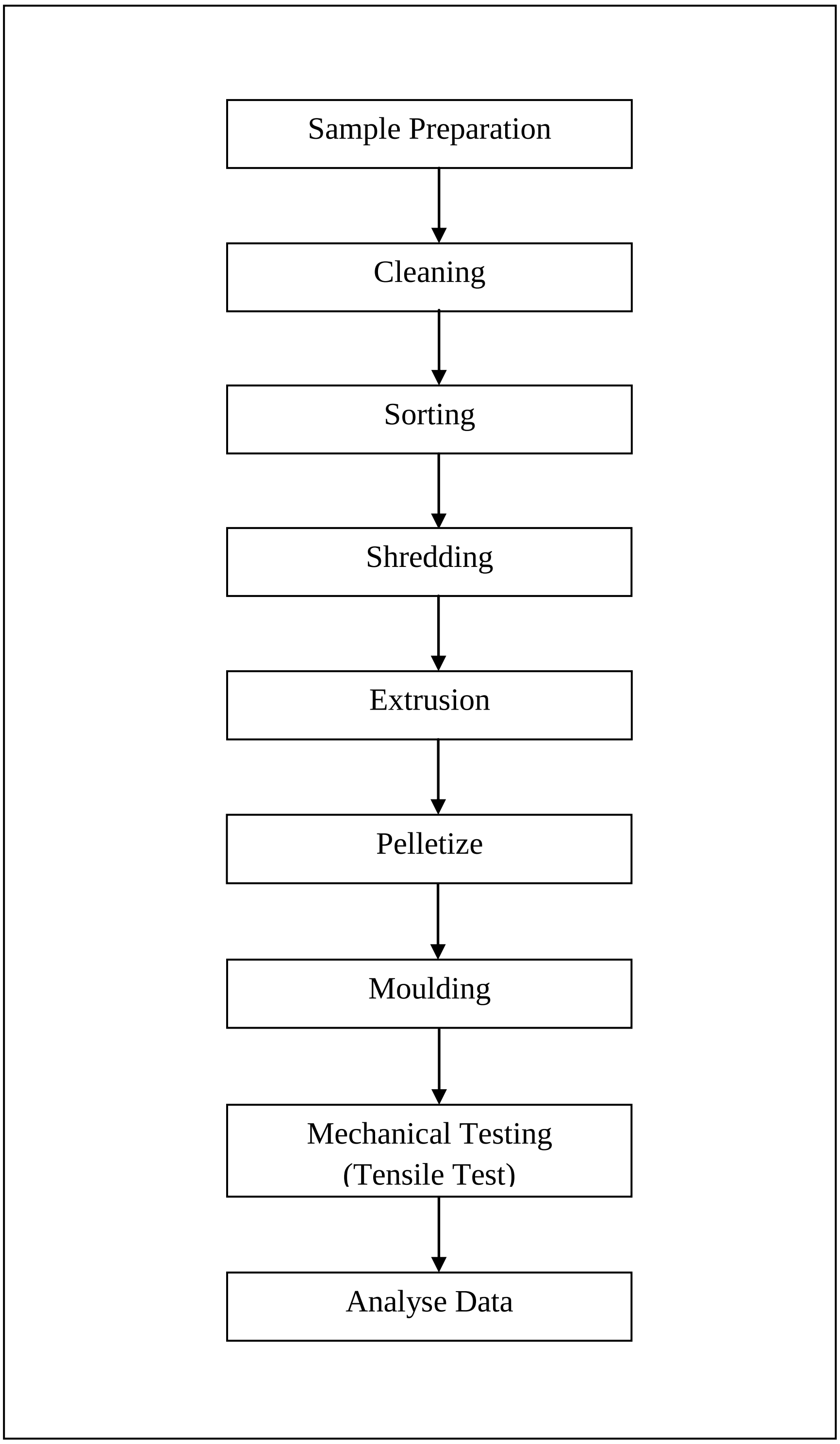

Figure 3.4: Experimental workflow

3.3.1. Sample collection

All sample of coastal waste plastics are collected at the beach around Kuantan. There are three beaches spotted to be an ideal area for sample collection due to large amount of plastic wastes can be found along the seashore. They are Pantai Lagenda (Pekan), Pantai Sepat (Kuantan) and also Pantai Balok (Kuantan). In order to get better results, all samples were collected within the tidal zone of beaches.

3.3.2. Sample Cleaning

All samples collected will be cleaned. The cleaning phase consists of washing and drying the plastics. It is very important that the plastics due to clean materials will definitely improve the quality of the end product. The plastics can be washed at different steps of processing, either before, after or even during sorting process. In this experiment, the plastics are washed manually by using boiled waster. As with washing, the plastics will be dried manually by spread out in the sun and regularly turned it.

3.3.3. Sorting Process

The sample taken should be various type of common plastic and they cannot be classified just by naked eyes. So, in order to categorize them into type of polymer, several simple tests can be used. The tests should be done are The Water Test, Burning Test, and also Fingernail Test.

For Water Test, a small piece of sample will be put into a mixture of water and a few drops of detergents. Then, just simply observe if the sample floats. For Burning Test, by using tweezers, hold a piece of sample then apply a fire on it. Later, just see if the sample burnt and what is the colour of flame appear on the sample. For Fingernail Test, just scratch the sample by using fingernail and examine whether the sample will be scratch or not. The result obtained will categorize the sample according to the type of plastic as follow:

Table 3.2: Results for water, scratch, and burning test.

Test	PE	PP	PVC
Water	Floats	Floats	Sinks
Scratch	Yes	No	No
Burning	Blue flame with yellow tip, melts and drips	Yellow flame with blue base	Yellow, sooty smoke. Does not continue to burn if flame is removed
Smell After Burning	Like candle wax	Like candle wax – less strong than PE	Hydrochloric acid

3.3.4. Shredding Process

Shredding is a process of making the raw material into pieces prior to extrusion process. In order to facilitate the extrusion process, the raw materials to be fed into the shredder should be cleaned and according to polymer type. The end products of shredding process are irregularly shaped pieces of plastics. Different type of plastics may be mix to a certain extent in order to get desired quality of end product depends on quality and type of raw material. However, in this experiment, the raw material will be shredded according to type of polymer.

Figure 3.5: Shredding machine

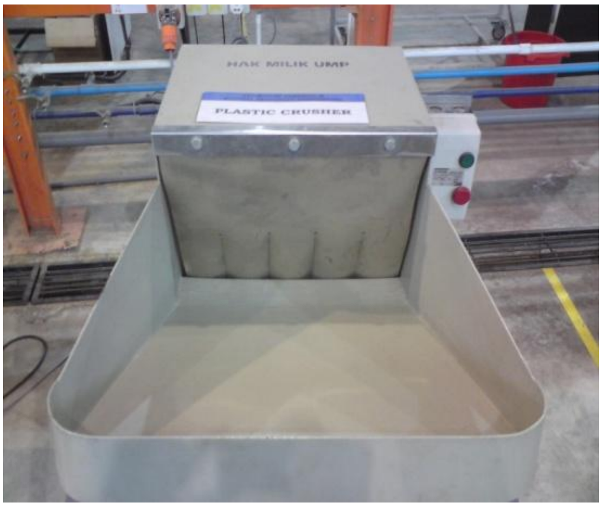

Figure 3.6: Feeding area

3.3.5. Extruding Process

Extruding process plays an important role in this experiment. The major role of the extrusion phase are compounding or mixing the various substance, homogenization, compression, degassing, plasticisation and melt filtration. In the extrusion process, the shredded plastics are fed into the hopper of the extruder. The plastics then are picked up from the hopper by rotating screw and forced down the barrel to the die head. Plasticization is caused by heat from both friction and the heating elements and the unique geometry of the rotating screw compressed the plastics. Just before the melted plastics get in touch with the die head, they are forced through a filter screen to take out any solid particles mixed with the melted plastics. The continuous-cylinder-profile that comes out from the extrusion die head then cooled by ventilator.

There are 5 heating elements in the extruder. In plasticization process, the temperature of each heating elements need to be adjusted according to melting temperature of each polymer. The temperature for each heating elements are as follows:

Table 3.3: Temperature profile of heating element for each polymer

Type of Polymer	Temperature of Heating Element (°C)				
	1	2	3	4	5
PP	170	180	190	180	170
PVC	225	240	250	240	225
PE	130	140	145	140	130
PET	235	250	265	250	235

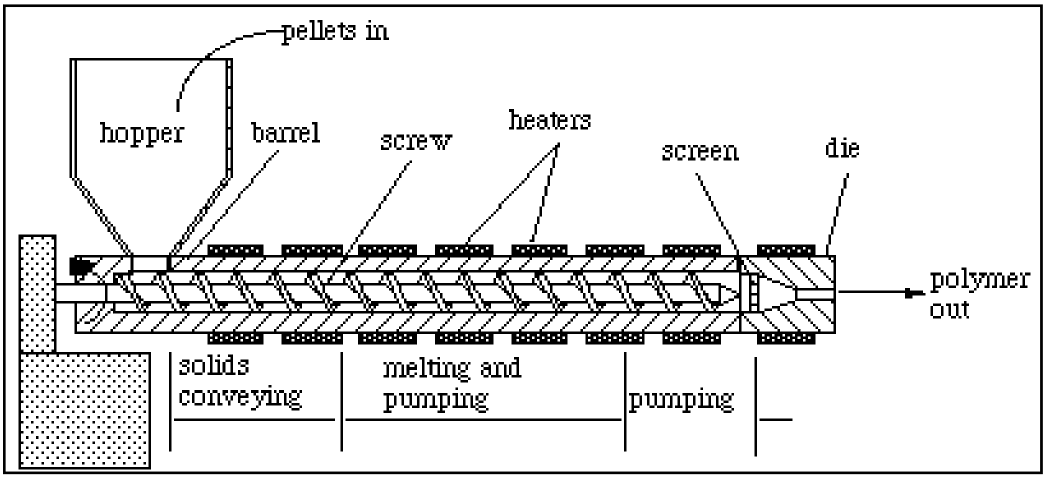

Figure 3.7: Mechanism of extruding process

3.3.6. Pelletizing Process

Normally, the shredded plastic wastes are palletized. Thus, the quality of the moulded end products can be enhanced. The use of pallets will boost up the effectiveness of the moulding process, due to the lower bulk density of shredded plastic wastes compared to pallet form. In this process, the continuous profile product from extruder will be chopped into cylindrical, short and uniform pallets that are ready for moulding process. The production capacity of the palletizing process depends on the size of the die head of extruder used.

3.3.7. Injection Moulding

The injection moulding mechanism is just the same as process of extrusion. However, the difference between these two processes is at the final zone where the injection moulding has very specific die for very specific geometry of final product but for extrusion process, it only has die that just create continuous profile of product. The geometry for final product from injection moulding is width = 2.90mm, gauge length = 28.04mm, and thickness = 3.94mm.

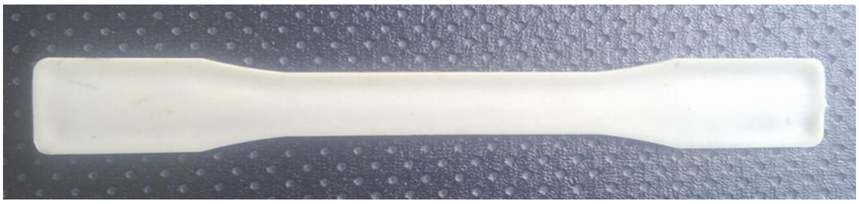

Figure 3.8: Final product of injection moulding for Polypropylene sample

3.3.8. Tensile Test

Tensile test is performed to identify some mechanical properties of coastal plastic waste. They are Tensile Strength, Modulus of Elasticity and Percent Elongation. Workflows for tensile test are as follow:

(i) Measure the length, width and thickness of each specimen.

(ii) Switch on the Universal Testing Machine (UTM) and the computer connects to UTM.

(iii) Open Shimadzu Trapezium X version 1.1.3 software, select testing method, and calibrate reading on software and testing machine. Name all specimens in the software.

(iv) Put the specimens at crosshead on testing machine. The specimens will be placed as in Figure 3.8.

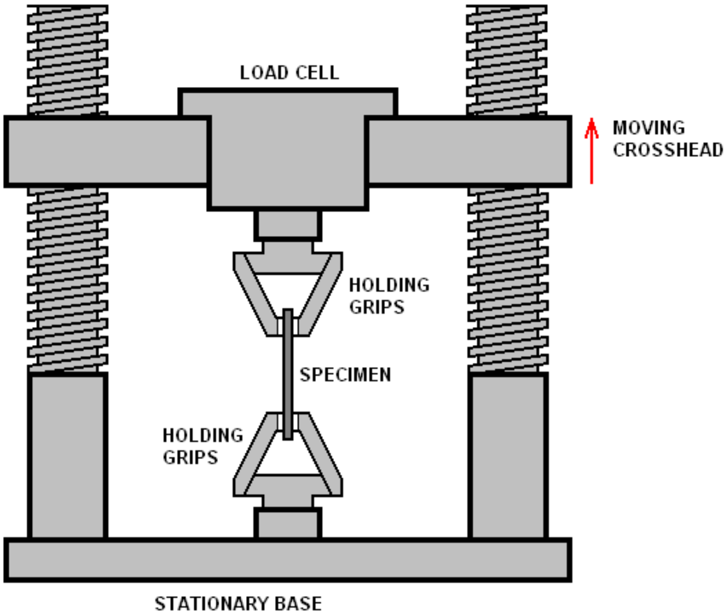

Figure 3.9: Tensile test

(v) Set the value stroke to zero.

(vi) Click the start button. The crosshead on the testing machine starts to move upward and pull the specimen. The maximum force value will be shown on the software after the specimen breaks into two pieces.

(vii) To remove the specimen, loosen both grips and take out the specimen.

(viii) For next test, press “re-test” button on the software. The crosshead will move to its original place. Repeat step (iv) until (viii)

(ix) Close the software. Shut down the computer.

3.3.9. Result Analysis

After finishing all the testing required, the samples of Polypropylene, Polyvinyl Chloride, Polyethylene and Polyethylene Terephthalate will be analyzed by comparing the results obtained with the data of virgin polymers.

CHAPTER 4

RESULT AND DISCUSSION

4.1. RESULT

4.1.1. Polypropylene

After performing Tensile Test using Universal Testing Machine, all results obtained shows a significant difference in term of Tensile Strength, Modulus of Elasticity and also Percentage of Elongation. The average Tensile Strength for coastal plastic waste of Polypropylene was 33.33MPa while the average Modulus of Elasticity for this type of polymer was 1178.38MPa. Meanwhile, the value for Elongation obtained was 5.04%. Based on data gained for both virgin and coastal plastic waste of Polypropylene, the percentage difference for Tensile Strength is about 18.91% and for Modulus of Elasticity is 23.98%. For Elongation, the percentage difference is about 94.96%.

Table 4.1: Differences between experimental and virgin data for coastal plastic waste of Polypropylene

Properties	Data		Percentage Difference (%)
	Experiment	Virgin	
Tensile Strength (MPa)	33.33	41.10	18.91
Modulus of Elasticity (MPa)	1178.38	1550.00	23.98
Percentage Elongation (%)	5.04	100.00	94.96

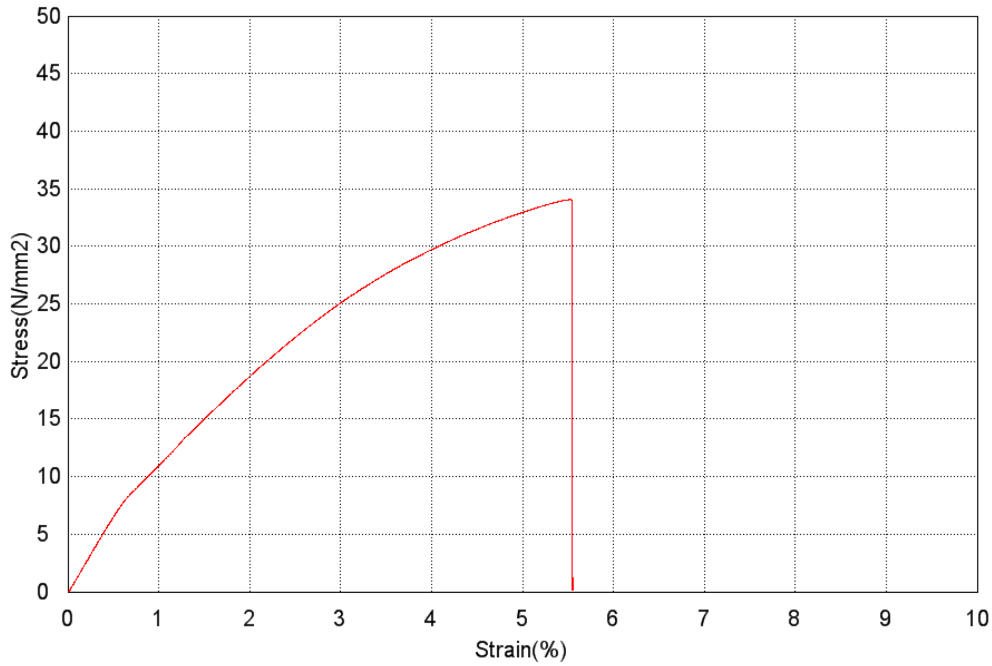

Figure 4.1: Stress-strain graph for sample of coastal plastic waste of Polypropylene number 1

4.1.2. Polyethylene

The result of Tensile Test obtained proves that selected mechanical properties of coastal plastic waste of Polyethylene differ slightly from virgin Polyethylene. The average Tensile Strength for coastal plastic waste is found to be 34.45MPa and it is almost 12.00% higher than virgin Polyethylene, which is 31.00MPa. Meanwhile, the Average Elongation for coastal plastic waste is only 5.94% while the virgin is about 10.00%. That means the coastal plastic waste experience a decrease of 40.60% in term of Percentage Elongation. For Modulus of Elasticity, the average value of coastal plastic waste is about 1414.23MPa. This value is actually 30.95% higher than virgin Polyethylene which is 1080.00MPa. All data of mechanical properties for virgin and coastal plastic waste of Polyethylene illustrated as in Table 4.2.

Table 4.2: Differences between experimental and virgin data for coastal plastic waste of Polyethylene

Properties	Data		Percentage Difference (%)
	Experiment	Virgin	
Tensile Strength (MPa)	34.45	31.00	11.13
Modulus of Elasticity (MPa)	1414.23	1080.00	30.95
Percentage Elongation (%)	5.94	10.00	40.60

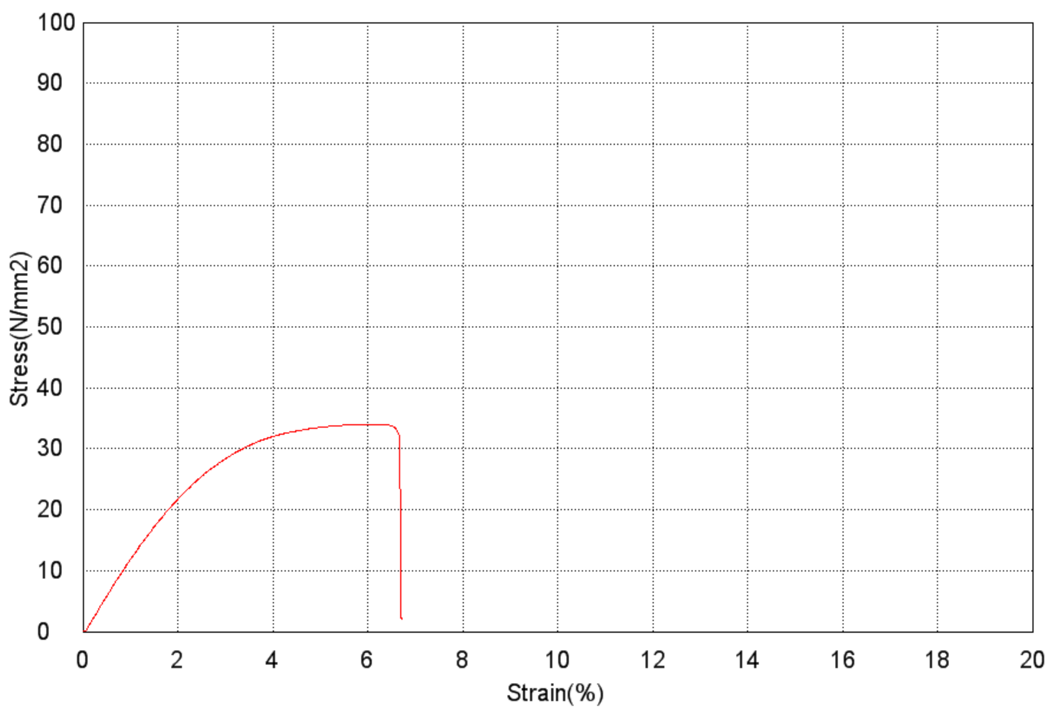

Figure 4.2: Stress-strain graph for sample of coastal plastic waste of Polyethylene number 1

4.1.3. Polyvinyl Chloride

The results for mechanical properties of coastal plastic waste of Polyvinyl Chloride also demonstrate a clear difference from the properties for virgin Polyvinyl Chloride in term of Tensile Strength, Modulus of Elasticity and also Percentage Elongation. Tensile Strength for coastal plastic waste is almost 23.94MPa and 40.70MPa for virgin Polyvinyl Chloride which means the Tensile Strength of Polyvinyl Chloride decreased by 41.18% when expose to natural environment of seashore. In the meantime, the Modulus of Elasticity for coastal plastic waste was found to be 1119.04MPa and it is decreased by almost 53.57% from its virgin which is 2410.00MPa. in term of Percentage Elongation, the average value of coastal plastic waste is about 7.06%. This value is actually 82.35% lower than the value of virgin Polyvinyl Chloride which is 40.00%. Table 4.3 shows all data of mechanical properties for virgin and coastal plastic waste of Polyvinyl Chloride.

Table 4.3: Differences between experimental and virgin data for coastal plastic waste of Polyvinyl Chloride

Properties	Data		Percentage Difference (%)
	Experiment	Virgin	
Tensile Strength (MPa)	23.94	40.70	41.18
Modulus of Elasticity (MPa)	1119.04	2410.00	53.57
Percentage Elongation (%)	7.06	40.00	82.35

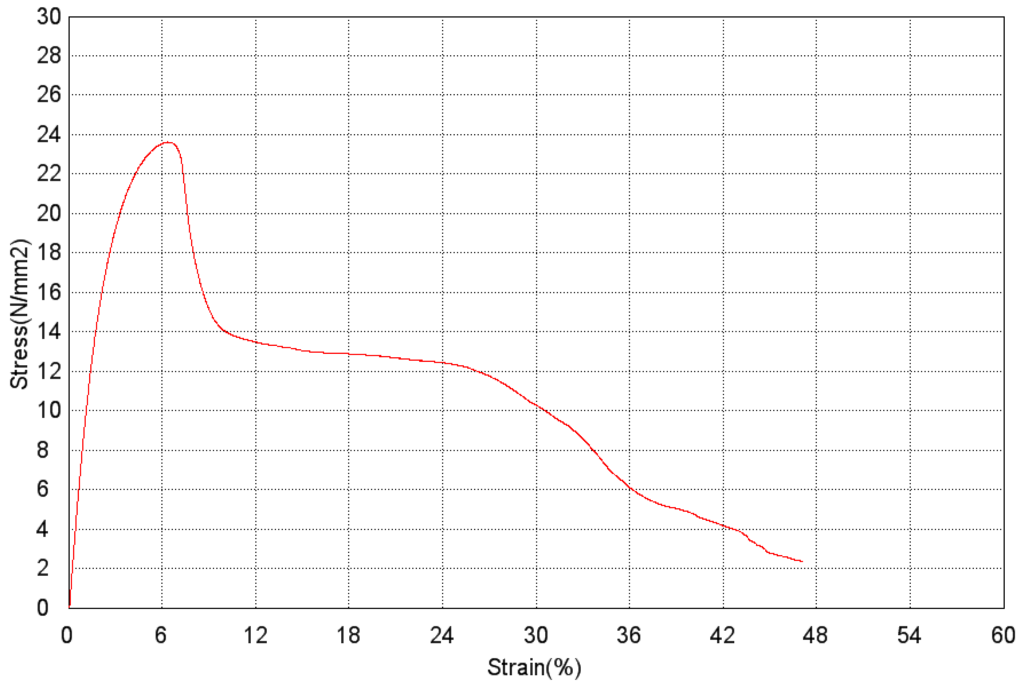

Figure 4.3: Stress-strain graph for sample of coastal plastic waste of Polyvinyl Chloride number 3

4.1.4. Polyethylene Terephthalate

From Tensile Test performed using Universal Testing Machine, all results obtained shows a significant difference in term of all selected mechanical properties. The average Tensile Strength for coastal plastic waste of Polyethylene Terephthalate was 28.71MPa and it is decreased by almost 64.11% from its virgin value which is 80.00MPa. The average Modulus of Elasticity for coastal plastic waste is found to be 1702.24MPa and it is almost 40.00% lower than virgin Polyethylene Terephthalate, which is 2800.00MPa. In the meantime, the average Elongation of coastal plastic waste is just 1.59%. This value is actually 97.35% lower than virgin Polyethylene Terephthalate which is 60.00%. All data of mechanical properties for virgin and coastal plastic waste of Polyethylene Terephthalate illustrated as in Table 4.4.

Table 4.4: Differences between experimental and virgin data for coastal plastic waste of Polyethylene Terephthalate

Properties	Data		Percentage Difference (%)
	Experiment	Virgin	
Tensile Strength (MPa)	28.71	80.00	64.11
Modulus of Elasticity (MPa)	1702.24	2800.00	39.21
Percentage Elongation (%)	1.59	60.00	97.35

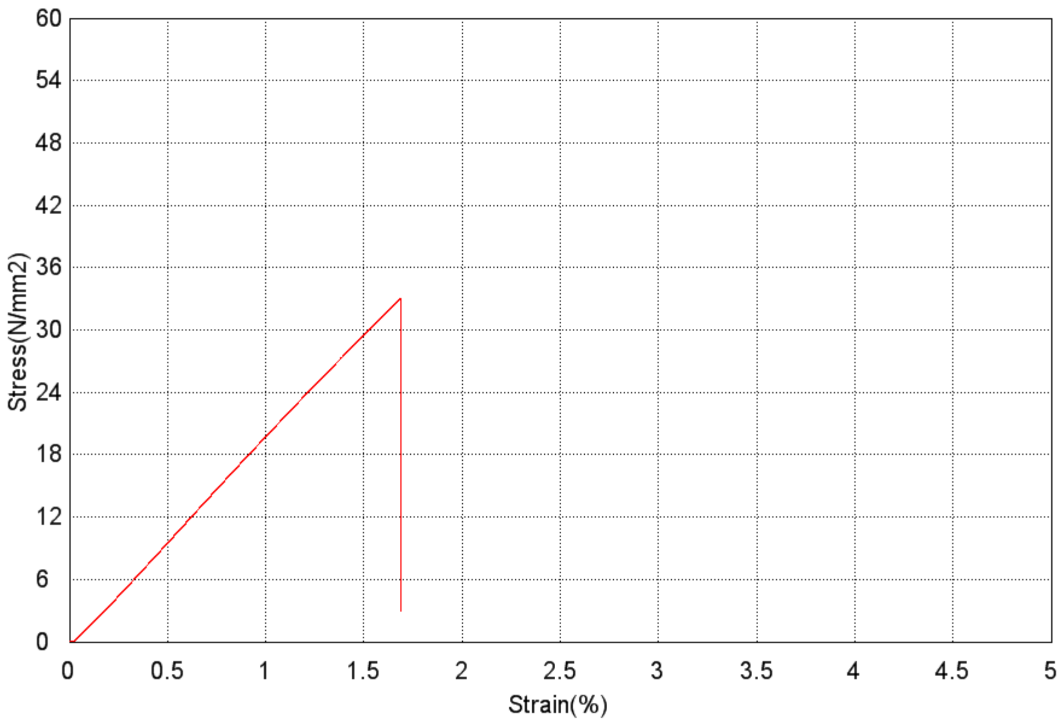

Figure 4.4: Stress-strain graph for sample of coastal plastic waste of Polyethylene Terephthalate number 5

4.2. DISCUSSION

From previous section, the mechanical properties studied for all selected type of polymers which are Polypropylene, Polyethylene, Polyvinyl Chloride and also Polyethylene Terephthalate show significant different in term of Modulus of Elasticity, Tensile Strength and also Percentage Elongation. These differences as a result of degradation of polymers especially due to light and Oxygen present around coastal area. The chemical reactions engaged in degradation lead to physical and chemical properties changes relative to their initially physical and chemical properties.

4.2.1. Thermal Degradation

In general, thermal degradation involves some changes to the polymer's molecular weight and molecular weight distribution. Also, this type of degradation involve typical changes include reducing embrittlement and ductility, chalking, changes in term of colour, cracking and reduction in most physical properties. Generally, almost all types of degradation follow similar basic flow and the same goes to thermal degradation. The major steps of thermal degradation are initiation, propagation and termination.

In initiation step of thermal degradation, the polymer chain will loss Hydrogen (H) atom as a result of energy input from light or heat. This reaction will generate unstable and highly reactive polymer free radical and H atom with an unpaired electron (H*).

In the propagation step, there are several of reactions involved. One of them is where the free radical reacts with Oxygen (O_2) molecule to form a peroxy radical which has ability to remove H atom from a different polymer chain to form a hydroperoxide and so regenerate free radical. Then, the hydroperoxide may form another two new free radicals which will keep on propagating the reaction to other polymer molecules.

Then, in the termination step, inert products will be created by reaction of all free radicals with each other and others polymer chains. Figure 4.5 shows the step of initiation, propagation and termination for thermal degradation.

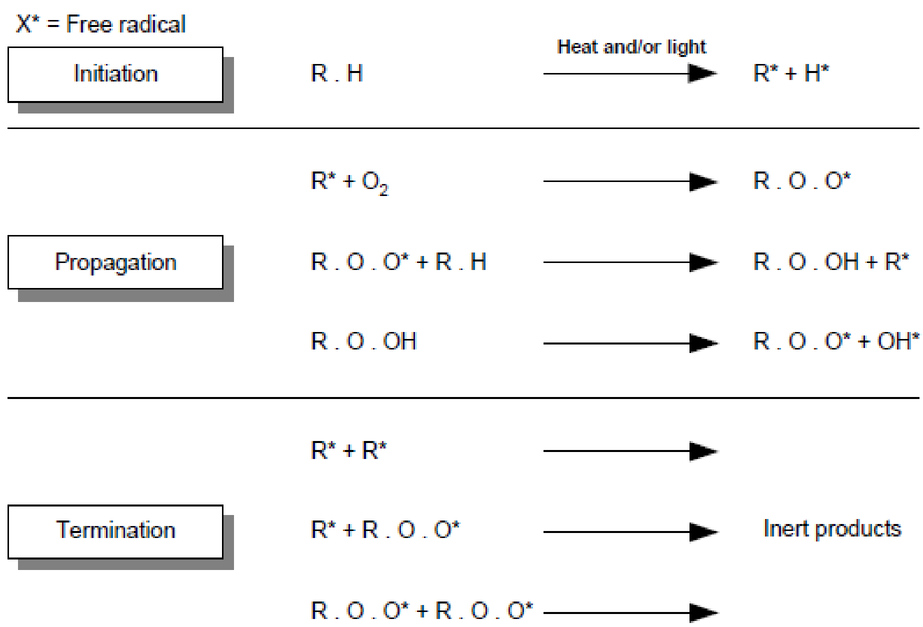

Figure 4.5: Step of initiation, propagation and termination for thermal degradation

Source: Zeus Industrial Product (2005)

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1. CONCLUSION

As the conclusion, the selected mechanical properties for all samples studied can be determined using Tensile Test via Universal Testing Machine. All mechanical properties studied include Modulus of Elasticity, Tensile Strength and also Percentage Elongation for all types of coastal plastic wastes consist of Polyethylene, Polypropylene, Polyethylene Terephthalate and Polyvinyl Chloride can be identified. However, all the properties recognized seem to differ from the virgin polymer. Table 5.1 shows properties and differences between coastal waste polymer and virgin polymer.

Table 5.1: Properties of all selected mechanical properties for selected type of polymers.

		PP	PE	PVC	PET
Tensile Strength	Experimental (MPa)	33.33	34.45	23.94	28.71
	Virgin (MPa)	41.10	31.00	40.70	80.00
	Percentage Difference (%)	18.91	11.13	41.18	64.11
Modulus of Elasticity	Experimental (MPa)	1178.38	1414.23	1119.04	1702.24
	Virgin (MPa)	1550.00	1080.00	2410.00	2800.00
	Percentage Difference (%)	23.98	30.95	53.57	39.21
Percentage Elongation	Experimental (MPa)	5.04	5.94	7.06	1.59
	Virgin (MPa)	100.00	10.00	40.00	60.00
	Percentage Difference (%)	94.96	40.60	82.35	97.35

5.2. RECOMMENDATION

There are some recommendation needs to be implemented in order to obtain better result and further study on production of useful product from coastal plastic waste can be performed. First, a study on other type of plastic waste should be conducted due the coastal waste are made of many type of polymers, including thermoplastic and also thermosetting plastic. This circumstance may reduce the number of coastal plastic waste thus may save the marine life while enhance the tourism sector. Second, a study on another property of polymer should be carried out such as Compressive Strength, Impact Strength, Flexural Strength, toughness, and so on. By identifying those mechanical properties, the difference between coastal plastic waste and also commercial plastic may be very clear and further study can be carried out to investigate the potential uses of coastal plastic waste. Last but not least, temperature profile during extrusion and injection moulding should be re-studied because certain polymers are much subjected to thermal degradation. Polypropylene is one of them. Polypropylene is very susceptible to thermal degradation, even at room temperature and should be protected against excessive heat.

REFERENCES

Amborski, L.E. & Flierl, D.W., (1953). *Physical Properties of Polyethylene Terephthalate Films,* 2290-2295, Nemours & Co., Inc., Buffalo, N. Y.

Biswas, P.K., Sengupta, S. and Basu, A.N. (1982) Mechanical Properties of Semicrystalline Polymer-Polypropylene. **19**, 215-224 Calcutta, India.

Callister, W.D. & Rethwisch, D.G. (2008). *Fundamental of Materials Science and Engineering* (3rd Edition ed.). John Wiley & sons, Inc.

Dimmock J. & Spedding C. E. (1970). *Creep testing of plastics composites.*

Hallam, M.A., Cansfield, D.L.M., Ward, I.M., and Pollard, G. (1986) A study of the effect of molecular weight on the tensile strength of ultra-high modulus polyethylenes. *Journal of Materials Science*. **21**, 4199-4205.

Haslinda, C.H., Mohmadisa, H., Suhaily, C.N., Hairy, I., Nasir, N. *Pencemaran Marin Di Pantai Timur Semenanjung Malaysia : Persepsi Pengunjung Di Kawasan Pelancongan Pantai Cahaya Bulan, Batu Buruk Dan Teluk Chempedak.*

Heidary, S. & Gordon B. (1994). *Hydrolyzable poly(ethylene terephthalate)*. Journal of Environmental Polymer Degradation 2: 19-26.

Hettige, H., Muthukumara, M. & David, W. (1998). *Industrial Pollution in Economic Development:*Kuznets Revisited.

Jansson, A., Moller, K. & Gevert, T. (2003). *Degradation of post-consumer polypropylene materials exposed to simulated recycling—mechanical properties,* Elsevier Ltd, Boras, Sweden.

La Mantia, F.P. (1992) Recycling of Heterogeneous Plastic Waste I –Blends with Low density Polyethylene. *Polymer Degradation and Stability*. **37**, 145-148. Palermo, Italy.

La Mantia, F.P. (1993) Recycling of Heterogeneous Plastic Waste II –The Role of Modifier Agents. *Polymer Degradation and Stability*. **42**, 213-218. Palermo, Italy.

Mills, W. H. and Turner, S., (1966) Tensile creep testing of thermoplastics, *Materials and Environmental Testing*, Institute of Mechanical Engineers, London.

Neilsen, L.E. & Landel, R.F. (1994) *Mechanical Properties Of Polymers And Composites*.

Othman, N. (2007) Characterisation and Properties of Bentonite/Polypropylene Composite. 8-49.

Smith, H.V. (1978) Some Criteria for the Successful Commercial Recycling of Heterogeneous Plastic Waste. *Conservation & Recycling*. **2**, 197-201. Pergamon Press Ltd., Great Britain.

Thomas, D.A. and Turner, S. (1969) 'Experimental Technique Inuniaxial Tensile Creep Testing'.

Toth, L.S., Lendvai, J. and Kovacs, I. (1985) The Plastic Behaviour of <100> and <111> Textured Polycrystalline Metals during Simultaneous Torsion an Extension. *Journal of Materials Science*. **20**, 3983-3987. Budapest, Hungary.

Tukker, A., Groot, H.D., Simons, L., and Wiegersma, S. (1999) Chemical Recycling of plastics waste (PVC and other resins), JA Delft, The Netherlands.

Utzig, J.& Gebauer, M. (1997) A new perspective for plastics recycling – to produce paraffin waxes from old plastics materials.

Wattayakorn, G. & Pernetta, J.C. (2007). *Reversing Environmental Degradation Trends in the South China Sea and Gulf of Thailand.*

APPENDIX A1

CALCULATION OF POLYPROPYLENE

Mechanical Properties of virgin Polypropylene

	Value	Unit
Modulus of Elasticity	1.55	GPa
Poisson's Ratio	0.40	
Yield Strength	31.00-37.20	MPa
Tensile Strength	41.10	MPa
Percent Elongation	100.00	%

Experimental Data

Average tensile strength

No of Test	Tensile Strength (MPa)
1	34.05
2	35.77
3	34.37
4	31.61
5	33.03

Average:

$$\bar{X} = \frac{34.05 + 35.77 + 34.37 + 31.61 + 33.03}{5}$$

$$\bar{X} = 33.33\ MPa$$

Percentage Difference between experimental data and virgin Polypropylene

$$\frac{41.10 - 33.33}{41.10} \times 100\% = 18.91\%$$

Average Modulus of Elasticity

No of Test	Modulus of Elasticity (MPa)
1	1265.99
2	1536.12
3	1122.97
4	1007.98
5	958.84

Average:

$$\bar{X} = \frac{1265.99 + 1536.12 + 1122.97 + 1007.98 + 958.84}{5}$$

$$\bar{X} = 1178.38\ MPa$$

Percentage Difference between experimental data and virgin Polypropylene

$$\frac{1550.00 - 1178.38}{1550.00} \times 100\% = 23.98\%$$

Average:Elongation

No of Test	Elongation (%)
1	5.51
2	6.19
3	4.98
4	4.06
5	4.45

Average:

$$\bar{X} = \frac{5.51 + 6.19 + 4.98 + 4.06 + 4.45}{5}$$

$$\bar{X} = 5.04\%$$

Percentage Difference between experimental data and virgin Polypropylene

$$\frac{100.00 - 5.04}{100.00} \times 100\% = 94.96\%$$

APPENDIX A2

CALCULATION OF POLYETHYLENE

Mechanical Properties of virgin Polyethylene

	Value	Unit
Modulus of Elasticity	1.08	GPa
Poisson's Ratio	0.46	
Yield Strength	26.20	MPa
Tensile Strength	31.00	MPa
Percent Elongation	10.00	%

Experimental Data

Average tensile strength

No of Test	Tensile Strength (MPa)
1	34.02
2	34.53
3	33.26
4	34.08
5	36.36

Average:

$$\bar{X} = \frac{34.02 + 34.53 + 33.26 + 34.08 + 36.36}{5}$$

$$\bar{X} = 34.45MPa$$

Percentage Difference between experimental data and virgin Polyethylene

$$\frac{31.00 - 34.45}{31.00} \times 100\% = -11.13\%$$

Average Modulus of Elasticity

No of Test	Modulus of Elasticity (MPa)
1	1370.21
2	1299.87
3	1457.76
4	1511.02
5	1432.28

Average:

$$\bar{X} = \frac{1370.21 + 1299.87 + 1457.76 + 1511.02 + 1432.28}{5}$$

$$\bar{X} = 1414.23 MPa$$

Percentage Difference between experimental data and virgin Polyethylene

$$\frac{1080.00 - 1414.23}{1080.00} \times 100\% = -30.95\%$$

Average:Elongation

No of Test	Elongation (%)
1	6.08
2	7.03
3	4.96
4	5.63
5	5.99

Average:

$$\bar{X} = \frac{6.08 + 7.03 + 4.96 + 5.63 + 5.99}{5}$$

$$\bar{X} = 5.94\%$$

Percentage Difference between experimental data and virgin Polyethylene

$$\frac{10.00 - 5.94}{10.00} \times 100\% = 40.60\%$$

APPENDIX A3

CALCULATION OF POLYVINYL CHLORIDE

Mechanical Properties of virgin Polyvinyl Chloride

	Value	Unit
Modulus of Elasticity	2.41	GPa
Poisson's Ratio	0.38	
Yield Strength	44.80	MPa
Tensile Strength	40.70	MPa
Percent Elongation	40.00	%

Experimental Data

<u>Average tensile strength</u>

No of Test	Tensile Strength (MPa)
1	23.62
2	23.85
3	24.19
4	23.95
5	24.15

Average:

$$\bar{X} = \frac{23.62 + 23.85 + 24.12 + 23.95 + 24.15}{5}$$

$$\bar{X} = 23.94MPa$$

Percentage Difference between experimental data and virgin Polyvinyl Chloride

$$\frac{40.70 - 23.94}{40.70} \times 100\% = 41.18\%$$

Average Modulus of Elasticity

No of Test	Modulus of Elasticity (MPa)
1	1085.85
2	1080.51
3	1233.78
4	1085.31
5	1109.73

Average:

$$\bar{X} = \frac{1085.85 + 1080.51 + 1233.78 + 1085.31 + 1109.73}{5}$$

$$\bar{X} = 1119.04MPa$$

Percentage Difference between experimental data and virgin Polyvinyl Chloride

$$\frac{2410.00 - 1119.04}{2410.00} \times 100\% = 53.57\%$$

Average:Elongation

No of Test	Elongation (%)
1	6.36
2	7.09
3	7.04
4	7.34
5	7.49

Average:

$$\bar{X} = \frac{6.36 + 7.09 + 7.04 + 7.34 + 7.49}{5}$$

$$\bar{X} = 7.06\%$$

Percentage Difference between experimental data and virgin Polyvinyl Chloride

$$\frac{40.00 - 7.06}{40.00} \times 100\% = 82.35\%$$

APPENDIX A4

CALCULATION OF POLYETHYLENE TEREPHTHALATE

Mechanical Properties of virgin Polyethylene Terephthalate

	Value	Unit
Modulus of Elasticity	2.80	GPa
Poisson's Ratio	0.44	
Tensile Strength	80.00	MPa
Percent Elongation	60.00	%

Experimental Data

<u>Average tensile strength</u>

No of Test	Tensile Strength (MPa)
1	22.42
2	30.39
3	22.83
4	34.88
5	33.01

Average:

$$\bar{X} = \frac{22.42 + 30.39 + 22.83 + 34.88 + 33.01}{5}$$

$$\bar{X} = 28.71MPa$$

Percentage Difference between experimental data and virgin Polyethylene Terephthalate

$$\frac{80.00 - 28.71}{80.00} \times 100\% = 64.11\%$$

<u>Average Modulus of Elasticity</u>

No of Test	Modulus of Elasticity (MPa)
1	1487.88
2	1592.79
3	1763.32
4	1788.43
5	1878.80

Average:

$$\bar{X} = \frac{1487.88 + 1592.79 + 1763.32 + 1788.43 + 1878.80}{5}$$

$$\bar{X} = 1702.24MPa$$

Percentage Difference between experimental data and virgin Polyethylene Terephthalate

$$\frac{2800.00 - 1702.24}{2800.00} \times 100\% = 39.21\%$$

<u>Average:Elongation</u>

No of Test	Elongation (%)
1	1.44
2	1.71
3	1.25
4	1.88
5	1.69

Average:

$$\bar{X} = \frac{1.44 + 1.71 + 1.25 + 1.88 + 1.69}{5}$$

$$\bar{X} = 1.59\%$$

Percentage Difference between experimental data and virgin Polyethylene Terephthalate

$$\frac{60.00 - 1.59}{60.00} \times 100\% = 97.35\%$$