Study on Thermal Degradation Effects on Physical Property of Polymers

by

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CERTIFICATION OF APPROVAL

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Approved by,

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(Assoc. Prof. Dr. Othman bin Mamat)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

ROHAIZAM BIN ABD RAHMAN

ABSTRACT

Polymer is a large molecule composed of repeating structural units connected by covalent chemical bonds. Polymer can be classified into thermoplastics and thermosets. The most significant difference in properties for both of thermoplastics and thermosets in environmental issues are thermoplastic polymers are recyclable while thermoset polymers are not recyclable. Thus, to prevent or reduce environmental pollution, a studies need to be carry out to accelerate degradation rate of the polymer. The main objectives of this project are to investigate and determine the differences of thermoplastic and thermoset polymer when undergo thermal degradation process. The most suitable materials for both thermoplastic and thermoset were selected which are HDPE for thermoplastic and phenolic for thermoset. The HDPE and phenolic were heated in the oven at five different temperatures (50, 70, 90, 105 and 120ºC) to undergo thermal degradation process. After the HDPE and phenolic were allowed to cool to room temperature, parameters changed after the heating process (thermal degradation) were measured. The parameters that were measured are the hardness and weight loss. The results showed that when both HDPE and phenolic undergo thermal degradation, the hardness of HDPE will decrease while for the penolic, the hardness will increase. For the weight loss, both HDPE and phenolic has the same properties which are the percentage of their weight loss will increase when they undergo thermal degradation. These differences between the thermoplastic and thermoset polymer after undergo thermal degradation process will be useful and important to prevent or reduce the environmental pollution.

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CHAPTER 1

INTRODUCTION

This chapter is dedicated to introduction and explanation of the project topic, “Study on Thermal Degradation Effects on Physical Property of Polymers”. A background about this Final Year Project is given followed by statement of the problem to be addressed and lastly the objectives and scope of the work are pointed out.

1.1 Background of Study

Polymer is a large molecule composed of repeating structural units connected by covalent chemical bonds [1]. Examples of polymers include plastics, DNA and proteins. Plastics is the general term for a wide range of synthetic or semisynthetic polymerization products. They are composed of organic condensation or addition polymers and may contain other substances to improve performance or reduce costs. Plastics can be formed into many different types objects, films, or fibres. Examples of plastics are polyvinyl chloride, polyethylene, polymethyl methacrylate and polyurethanes. Polymer can be classified into thermoplastics and thermosets. Thermoplastic is plastics that melt to a liquid when heated and freezes to a brittle, very glassy state when cooled sufficiently. Thermoplastic polymers differ from thermoset polymers as they can, unlike thermoset polymers, be remelted and remoulded. When heat is added, thermoplastic polymers become soft, remoldable and weldable while thermoset polymers cannot be welded or remolded, simply burning instead [2]. This will give a great difference in environmental issues since thermoplastic polymers are recyclable while thermoset polymers are not recyclable.

1.2 Problem Statement

Polymer degradation is a change in the properties of a polymer or polymer based product under the influence of one or more environmental factors such as heat, lights or chemicals. Degradation can be useful for recycling or reusing the polymer waste to prevent or reduce environmental pollution. A studies need to be carry out to accelerate degradation rate of the polymer to reduce environmental pollution.

1.3 Objectives

Along this project, there are some objective needs to be achieved which are:

1. To investigate and determine the differences of thermoplastic and thermoset polymer when undergo thermal degradation process.
2. To investigate the change in physical property of polymers during thermal degradation process.

1.4 Scope of Work

Scope of work of this project includes:

1. Investigation and selection of the most suitable polymer to be studied.
2. Investigation and determine the differences of thermoplastic and thermoset polymer when undergo thermal degradation process.
3. Measuring the hardness and weight loss that changed during degradation process.

1.5 Significant of the Work

Significant of this project is to determine the differences of thermoplastic and thermoset polymer when undergo thermal degradation process by executing a series of experimental measurement.

CHAPTER 2

LITERATURE REVIEW

2.1 Polymer Degradation Basics

Degradation can be defined as the scission process during which polymer chains are broken down to form oligomers (smaller units) and finally to form monomers [3]. The term erosion designates the loss of material due to monomers and oligomers leaving the polymer. Polymer degradation may be due to thermal, photo, mechanical or chemical exposure [4]. The degradation process can be useful from the view points of understanding the structure of a polymer or recycling the polymer waste to prevent or reduce environmental pollution. For example, polylactic acid and polyglycolic acid are two polymers that are useful for their ability to degrade under aqueous conditions. A copolymer of these polymers is used for biomedical applications such as hydrolysable stitches that degrade over time after they are applied to a wound. These materials can also be used for plastics that will degrade over time after they are used and will therefore not remain as litter [1].

Polymeric degradation has proven to be a difficult phenomenon to describe analytically, numerically, or empirically. In addition, many of the models that have been developed are unique to a specific material system and cannot be generalized [5]. Nowadays, there are primarily six commodity polymers in use, namely polyethylene, polypropylene, polyvinyl chloride (PVC), polyethylene terephthalate (PET), polystyrene and polycarbonate. These make up nearly 98% of all polymers and plastics encountered in daily life. Each of these polymers has its own characteristic modes of degradation and resistances to heat, light and chemicals. Polyethylene and polypropylene are sensitive to oxidation and ultraviolet (UV) radiation, while PVC may discolour at high temperatures due to loss of hydrogen chloride gas, and become very brittle. PET is sensitive to hydrolysis and attack by strong acids, while polycarbonate depolymerizes rapidly when exposed to strong alkalis [6]. Therefore, for a specific polymer, specific critical factors that will accelerate the degradation rate of that specific polymer need to be determined.

2.2 Modes of Polymer Degradation

Before choosing the critical factors that will accelerate the degradation of polymers, it is necessary to understand the mechanism or modes of polymer degradation since all the critical factors are the modes of initiation of the polymer degradation. These compromise thermal, mechanical, photochemical, radiation chemical, biological and chemical degradation of polymeric materials.

Thermal degradation refers to the case where the polymers, at elevated temperatures, starts to undergo chemical changes without the simultaneous involvement of another compound. Often it is rather difficult to distinguish between thermal and thermo-chemical degradation because polymeric materials are only rarely chemically “pure”. Impurities or additives present in the material might react with the polymeric matrix, if the temperature is high enough [7]. The example of thermal degradation can be seen at acrylic bulkhead light covers. The light covers suffered from discolouration, reduction in transparency, and embrittlement. The discolouration as indicated in Figure 2.1 was not uniformly distributed. It maximized in areas of the cover that were closest to both the tungsten filament light source and (rising) hot air. The radiation from tungsten light bulbs is characteristically low in UV and high in infrared intensity. Bulkhead light cover usually made of acrylate-modified polymethyl methacrylate (PMMA) which has excellent resistance to photo-oxidation but modest resistance to thermo-oxidation [8]. Therefore, the discolouration, loss of transparency, and embrittlement of acrylic bulkhead light cover were primarily due to thermal degradation which is contributed by excessive heat.

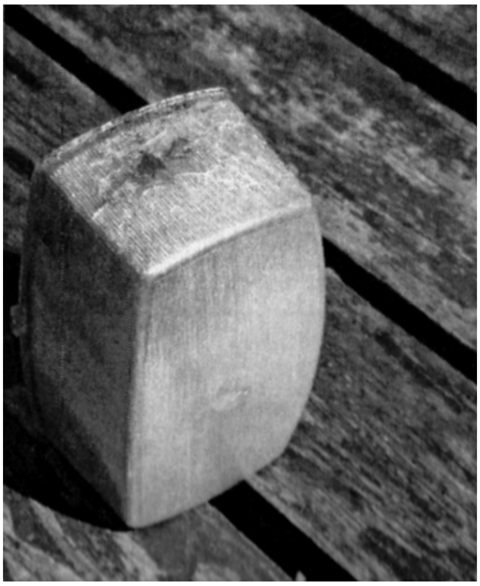


Figure 2.1: A cracked and discoloured bulkhead light cover

Light-induced polymer degradation, or photodegradation, concerns the physical and chemical changes caused by irradiation of polymers with UV or visible light. In order to be effective, light must be absorbed by the substrate. Thus, the existence of chromophoric (light absorbing) groups in the macromolecules (or in the additives) is a prerequisite for the initiation of photochemical reactions. Generally, photochemically important chromophores absorb in the UV range (at wavelengths below 400nm). The importance of photodegradation of polymers derives, therefore, from the fact that the UV portion of the sunlight spectrum can be absorbed by various polymeric materials. The resulting chemical processes may lead to severe property deteriorations [7]. Many natural and synthetic polymers are attacked by UV radiation and products made using these materials may crack or disintegrate. Continuous is a more serious problem than intermittent exposure, since attack is dependent on the extent and degree of exposure to sunlight. Common synthetic polymers which may be attacked include polypropylene and low density polyethylene (LDPE) where tertiary carbon bonds in their chain structures are the centers of attack. The UV rays activate such bonds to form free radicals, which then react further with oxygen in the atmosphere, producing carbonyl groups in the main chain. The exposed surfaces of products may then discolour and crack, although in bad cases, complete product disintegration can occur. In fibre products like polypropylene rope used in outdoor applications, product life will be low because the outer fibres will be attacked first, and will easily be damaged by abrasion for example [9]. Discolouration of the polypropylene rope may also occur, so giving an early warning of the photodegradation as shown in Figure 2.2.

Figure 2.2: Effect of photodegradation on polypropylene rope

Many degradation phenomena and processes that lead to a deterioration in material properties are grouped under the terms ‘chemical attack’ or ‘chemical incompatibility’. These include oxidation, hydrolysis, halogenation, and other processes involving irreversible modifications to a polymer’s molecular structure by chemical reaction with a fluid [8]. All of these processes are grouped under chemical degradation. Chemical degradation refers exclusively to process which are induced under the influence of chemicals (acids, bases, solvents, reactive gases) brought into contacts with polymers. In many such cases, a significant conversion is observed, however, only at elevated temperatures because the activation energy for these process is high [7]. The example of chemical degradation can be seen at nylon moulded connector in the diesel line. Nylon is sensitive to degradation by acids (hydrolysis) and nylon mouldings will crack when attacked by strong acids [6]. Hydrolysis is a form of chemical degradation resulting from contact with water, or more precisely with the hydrogen ions (H^+) or hydroxyl ions (OH^-) in water. The term is also used to describe similar degradation resulting from contact with other water containing fluids such as acids (increased H^+ concentration) and alkalis (increased OH^- concentration) that may accelerate hydrolysis [8]. A fuel pipe fractured when a small drip of 40% sulphuric acid from a nearby lead-acid battery fell onto a nylon 6,6 moulded connector in the diesel line. The crack grew with time until it penetrated the interior, so initiating a slow leak of diesel. The crack continued to grow until final separation occurred as shown in Figure 2.3 and 2.4, and diesel fuel poured into the road [6].

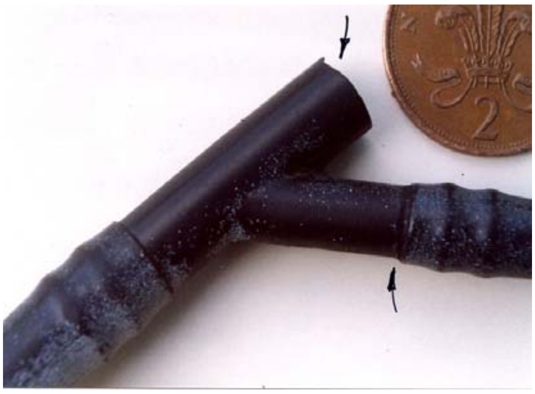


Figure 2.3: Broken fuel pipe

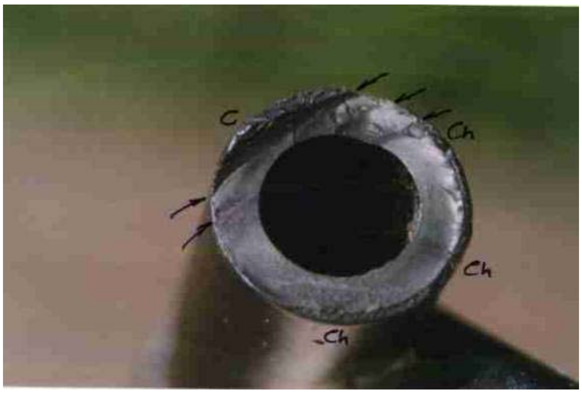


Figure 2.4: Cross section of broken fuel pipe

Biologically initiated degradation also is strongly related to chemical degradation as far as microbial attack is concerned. Microorganisms (e.g. algae, fungi, actinomycetes, protozoa, and bacteria) produce a great variety of enzymes which are capable of reacting with natural and synthetic polymers. The enzymatic attack of the polymer is a chemical process which is induced by the microorganisms in order to obtain food (the polymer serves as carbon source). The microbial attack of polymers occurs over a rather wide range of temperatures. Optimum proliferation temperatures as high as 60ºC or 70ºC are not uncommon [7]. If the microorganisms have access to water (or moisture) and nutrients, they will attach themselves to most surfaces and will multiply. The result is a highly hydrated layer of living and dead microorganisms, and their metabolic by-products. These are called biofilms, and the mixture of microorganisms within the film will depend upon such factors as temperature, pH, light intensity, access to oxygen and the types of nutrient that are available. The staining of polymers by lipophilic pigments is a common aesthetic problem in bathrooms and other warm and humid environments. Shower curtains and seals are prone to be stained red or pink. The pigments are capable of diffusing into the material bulk and therefore cleaning is impossible. The erratic incidence of pinking of unplasticised polyvinyl chloride (UPVC) window frames may also be due to this mechanism [8].

Mechanically initiated degradation generally refers to macroscopic effects brought about under the influence of shear forces. Apart from the important role polymer fracture plays in determining the applications of plastics, it should also be pointed out, that stress-induced processes in polymeric materials are frequently accompanied by bond ruptures in the polymer main-chains. This fact can be utilized for example for the mechanochemical initiation of polymerization reactions with the aim of synthesizing block and graft-copolymers [7]. Modest levels of stress applied over long periods of time induce purely mechanical degradation in the form of crazes and cracks. This is the underlying cause of the long term transition from ductile to brittle behaviour [8]. Embrittlement due to sustained prestressing or prestraining in air has been reported [10] for polycarbonate. The elongation at break without prestraining was 12%. After 175 hours at 0.5% the elongation at break was found to be unaffected but after the same period at 1.5% strain, ultimate elongation was reduced to 2%. There is sufficient evidence to suggest that there is a critical thermomechanical history (or combination of histories) that irreversible degrades the subsequent structural properties of all glassy amorphous thermoplastics. Furthermore this is induced by the initiation and growth of crazes and cracks that will lead to mechanical degradation. See Figure 2.5 below.

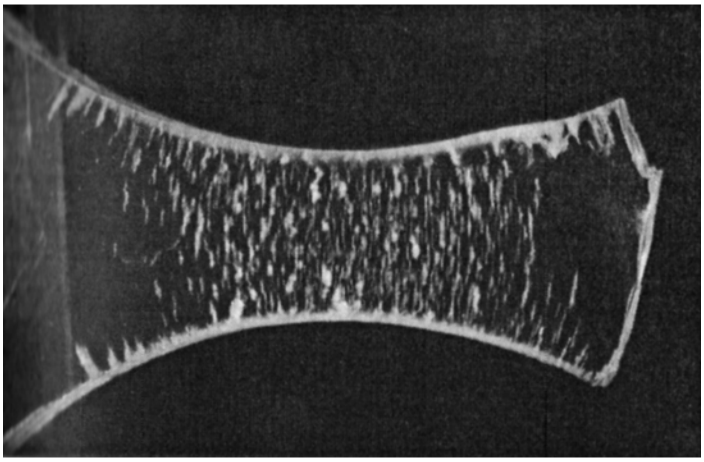


Figure 2.5: Crazes or ‘silver cracks’ developed in polycarbonate after long term stressing in air

Frequently, circumstances prevail that permit the simultaneous occurrence of various modes of degradation. Typical example is environmental processes, which involve the simultaneous action of UV light, oxygen and harmful atmospheric emissions. Another example is oxidative deterioration of thermoplastic polymers during processing, which is based on the simultaneous action of heat, mechanical forces and oxygen [7].

CHAPTER 3

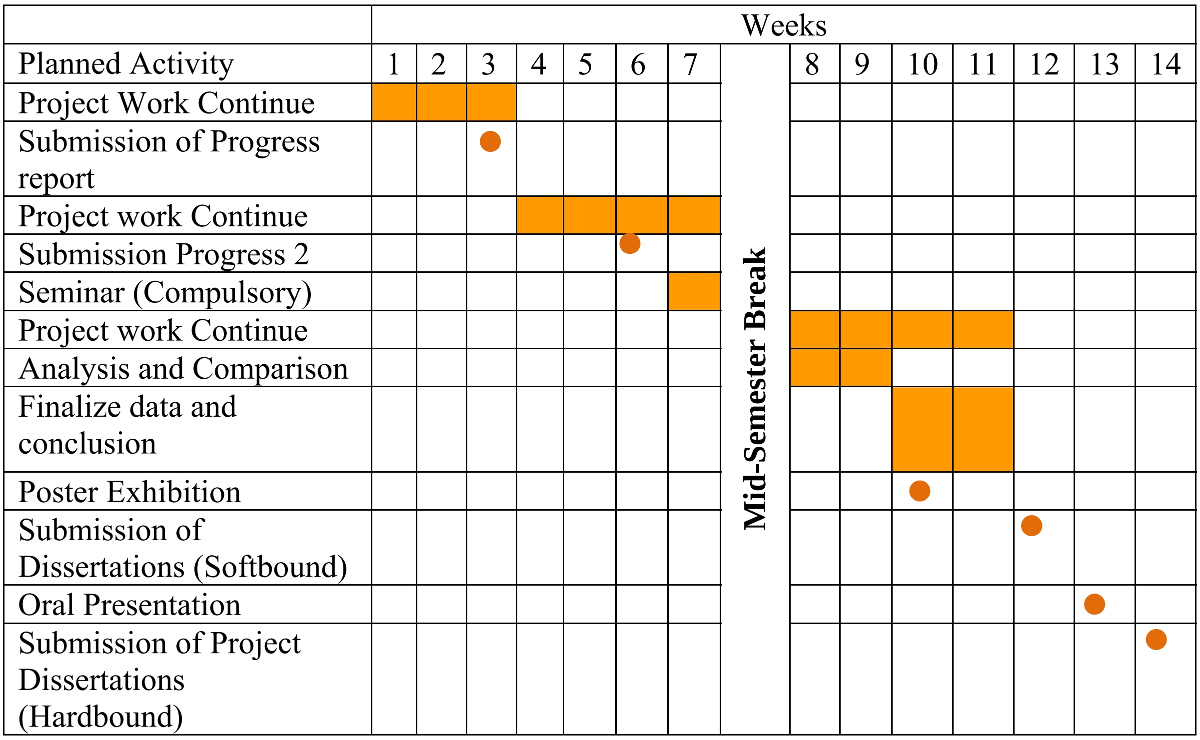
METHODOLOGY

To achieve the objective of this project, there are some steps required to be executed base on the engineering knowledge. The steps are:

1. Material selection
    - To investigate and decide the most suitable polymer to be studied.
2. Measurement
    - To conduct a series of experimental measurement to measure the parameters/properties those are changing during degradation process.

3.1 Gantt Chart

The project Gantt Chart is shown in Figure 3.1.



	Weeks														
Planned Activity	1	2	3	4	5	6	7		8	9	10	11	12	13	14
Project Work Continue	🟧	🟧	🟧					Mid-Semester Break							
Submission of Progress report			●												
Project work Continue				🟧	🟧	🟧	🟧								
Submission Progress 2						●									
Seminar (Compulsory)							🟧								
Project work Continue									🟧	🟧	🟧	🟧			
Analysis and Comparison									🟧	🟧					
Finalize data and conclusion											🟧	🟧			
Poster Exhibition											●				
Submission of Dissertations (Softbound)													●		
Oral Presentation														●	
Submission of Project Dissertations (Hardbound)															●

● Suggested Milestone
🟧 Planned Duration

Figure 3.1: Gantt Chart for the milestone of the project

3.2 Flow Chart of Execution Work

Figure 3.2 shows the project flow chart.

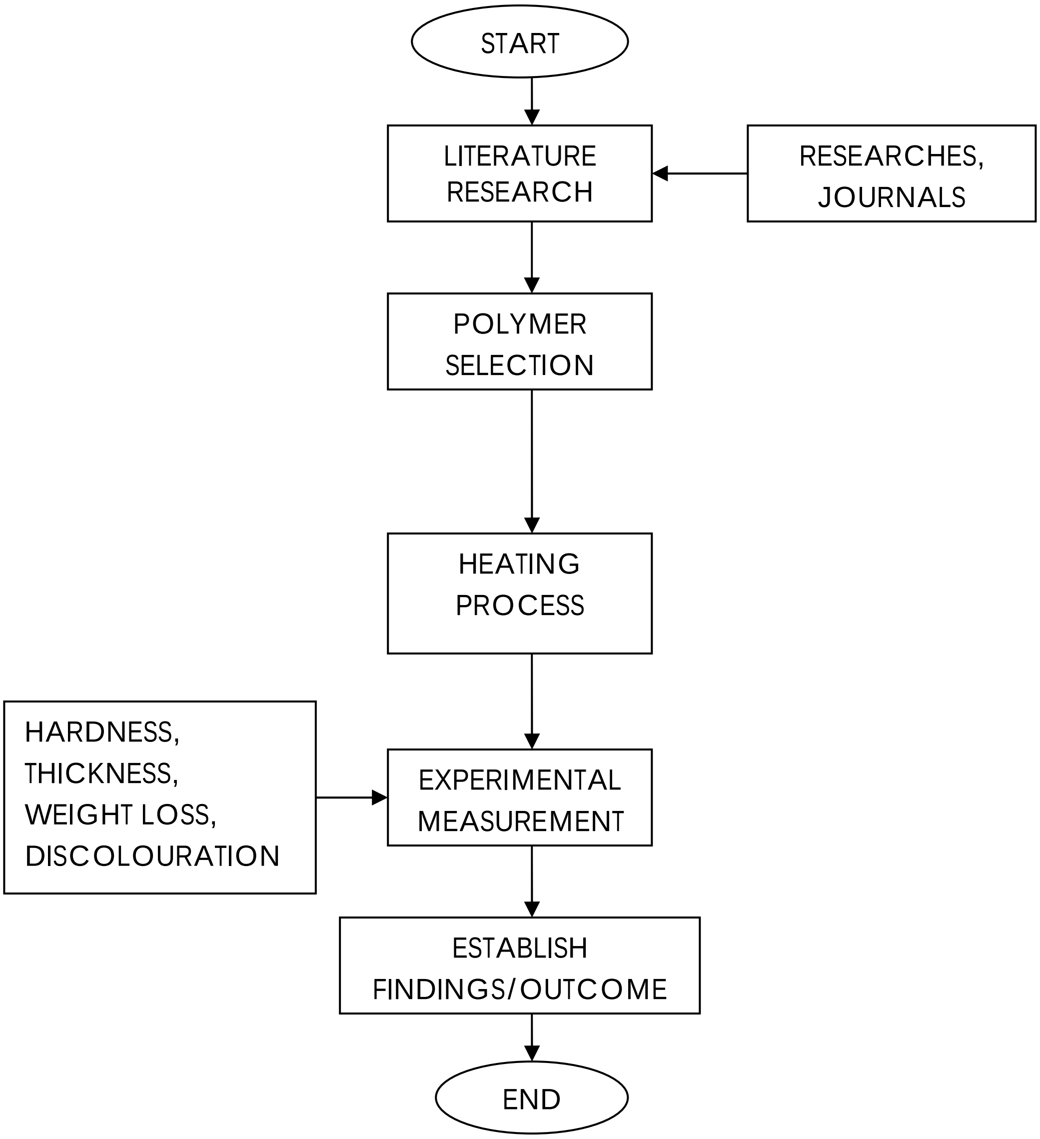


Figure 3.2: Flow chart of study on thermal degradation of polymer

3.3 Material

3.3.1 High Density Polyethylene (HDPE)

For the thermoplastic polymer, HDPE was chosen. HDPE used was manufactured by Titan Petchem (M) Sdn. Bhd with a melt flow index and a density of 7 g/min and 0.961 g/cm^3 respectively. Figure 3.3 shows a pack of HDPE available in the market.

Figure 3.3: Photograph of high density polyethylene

3.3.2 Phenolic

For the thermoset polymer, phenolic was chosen. Phenolic used was manufactured by Buehler Ltd with a density of 1.27g/cm^3. Figure 3.4 shows the phenolic available in the market.

Figure 3.4: Photograph of phenolic powder

3.4 Experimental Procedure

3.4.1 Heating Process (Oven)

For the heating process, HDPE and phenolic samples were brought to the CARBOLITE PN200 Oven to undergo thermal degradation. Example of the oven is shown in Figure 3.5. In accordance to the ASTM D618 – 00 and D3045 – 92, one set (five samples each set) of HDPE and 1 set of pnenolic were brought together into the oven and heated for five different temperatures (50, 70, 90, 105 and 120ºC). For each temperature, the samples will be heated for the duration of 6 hours. At the termination of the aging interval, the samples will be removed from the oven and allowed to cool to room temperature.

Figure 3.5: CARBOLITE PN200 Oven

3.4.2 Hardness Test

After the samples were allowed to cool to room temperature, parameters changed after the heating process (thermal degradation) will be measured. One of the parameters that will be measured is the hardness of the HDPE and phenolic. Hardness is generally referred to as a material's property that indicates resistance to surface penetration [11]. The hardness of each sample of HDPE and pnenolic will be measured before and after the heating process. For the materials that were used, which are the HDPE and phenolic, the most suitable hardness test method is the Rockwell hardness test method (using ½ in. steel ball indenter with load of 60kg) and the test were done in accordance of ASTM D785 – 03. The example of hardness testing machine is shown in Figure 3.6.

Figure 3.6: INDENTEC 9150LKV Hardness Test Machine

The Rockwell hardness test method consists of indenting the test material with a diamond cone or hardened steel ball indenter. The indenter is forced into the test material under a preliminary minor load *F0* (Figure 3.7A) usually 10 kgf. When equilibrium has been reached, an indicating device, which follows the movements of the indenter and so responds to changes in depth of penetration of the indenter is set to a datum position. While the preliminary minor load is still applied, an additional major load is applied with resulting increase in penetration (Figure 3.7B). When equilibrium has again been reach, the additional major load is removed but the preliminary minor load is still maintained. Removal of the additional major load allows a partial recovery, so reducing the depth of penetration (Figure 3.7C). The permanent increase in depth of penetration, resulting from the application and removal of the additional major load is used to calculate the Rockwell hardness number [12].

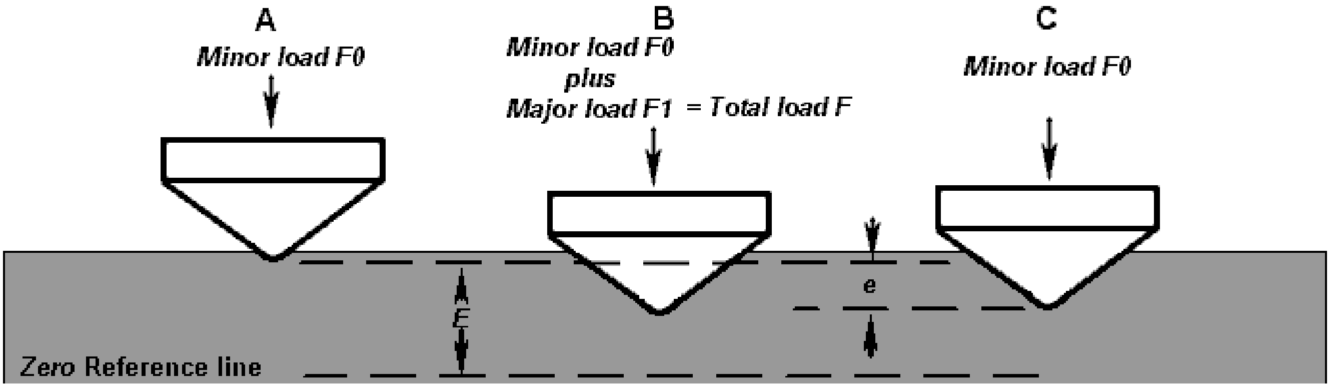


Figure 3.7: Rockwell Principle [12]

Rockwell hardness number was calculated by using this formula [12]:

$$\mathbf{HR} = E - e$$

$F0$ = preliminary minor load in kgf

$F1$ =additional major load in kgf

F = total load in kgf

e = permanent increase in depth of penetration due to major load F1 measured in units of 0.002 mm

E = a constant depending on form of indenter: 100 units for diamond indenter, 130 units for steel ball indenter

HR = Rockwell hardness number

D = diameter of steel ball

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results

Along this project, there are several properties of polymer or parameters that were measured as the evidence of the degradation and to investigate the differences of thermoplastic and thermoset polymer when undergo thermal degradation process. The properties of polymer or parameters that were measured include:

i) Hardness

The hardness of each sample was tested by using INDENTEC 9150LKV hardness testing machine which is applying Rockwell hardness test method. For each sample, 5 readings were taken and the average calculated.

ii) Weight lost

The weight lost of each sample was calculated by first, measure the weight of each sample before and after the heating process (thermal degradation) and then calculated by using this formula:

$$\Delta m = m_f - m_i$$

m_f = Mass of the sample after heating process (kg)
m_i = Mass of the sample before heating process (kg)
Δm = Loss in mass (kg)

For each sample, 5 readings of weight loss were taken and the average calculated.

4.1.1 Hardness

The average hardness calculated was shown in Table 4.1 and 4.2.

Table 4.1: Average hardness before and after heating for HDPE

Sample	Temperature, T (ºC)	Average Hardness	
		Before heating (HRR)	After heating (HRR)
A51	50	52.16	45.52
A52		47.68	42.10
A53		52.68	46.80
A54		40.64	36.28
A55		49.80	43.38
A41	70	49.96	41.26
A42		50.30	43.78
A43		49.32	43.12
A44		46.56	41.86
A45		45.74	37.06
A31	90	50.16	42.04
A32		46.74	37.70
A33		44.14	36.54
A34		50.66	40.02
A35		49.68	41.98
A21	105	45.12	36.60
A22		47.66	36.86
A23		49.06	38.28
A24		51.04	40.58
A25		50.84	39.06
A11	120	51.36	38.56
A12		50.72	38.66
A13		44.84	33.86
A14		46.72	34.98
A15		48.53	35.58

Table 4.2: Average hardness before and after heating for Phenolic

Sample	Temperature, T (ºC)	Hardness	
		Before heating (HRR)	After heating (HRR)
B51	50	123.40	123.54
B52		122.80	122.93
B53		123.54	123.69
B54		123.60	123.74
B55		123.72	123.86
B41	70	123.72	123.93
B42		123.80	124.02
B43		123.82	124.03
B44		122.94	123.15
B45		122.96	123.17
B31	90	123.60	123.89
B32		123.48	123.78
B33		122.98	123.29
B34		122.96	123.25
B35		123.78	124.10
B21	105	124.14	124.54
B22		123.72	124.11
B23		123.56	123.95
B24		122.64	123.03
B25		123.36	123.76
B11	120	123.50	123.97
B12		123.64	124.11
B13		122.94	123.43
B14		123.24	123.72
B15		123.26	123.73

The hardness versus temperature for both HDPE and phenolic was shown in Figure 4.1 and 4.2.

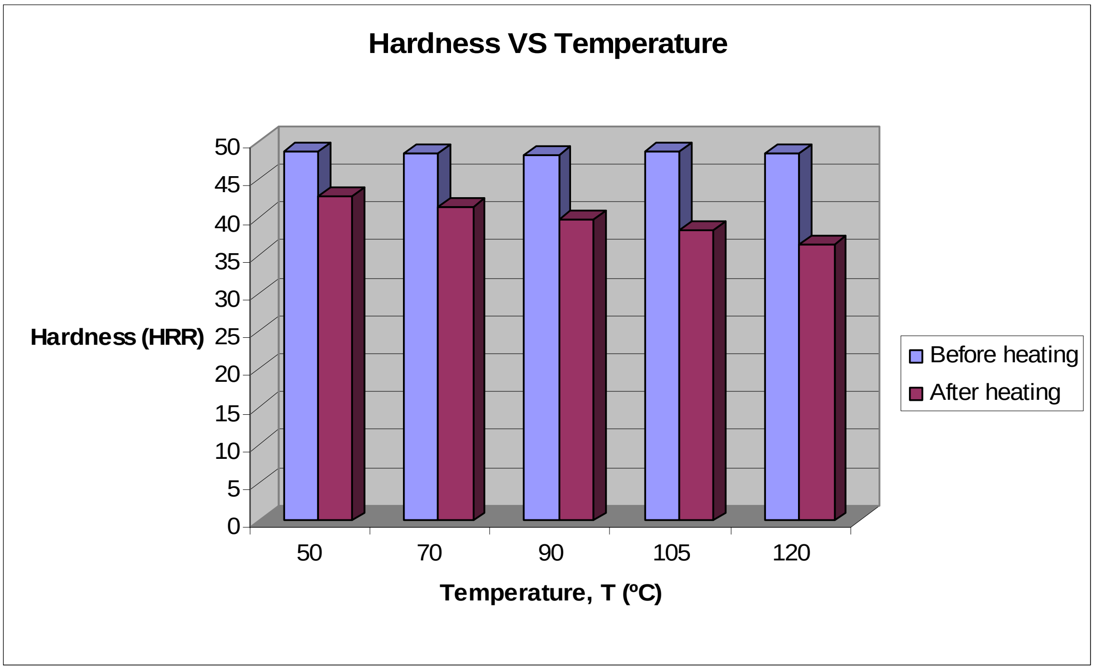


Figure 4.1: Hardness VS Temperature for HDPE

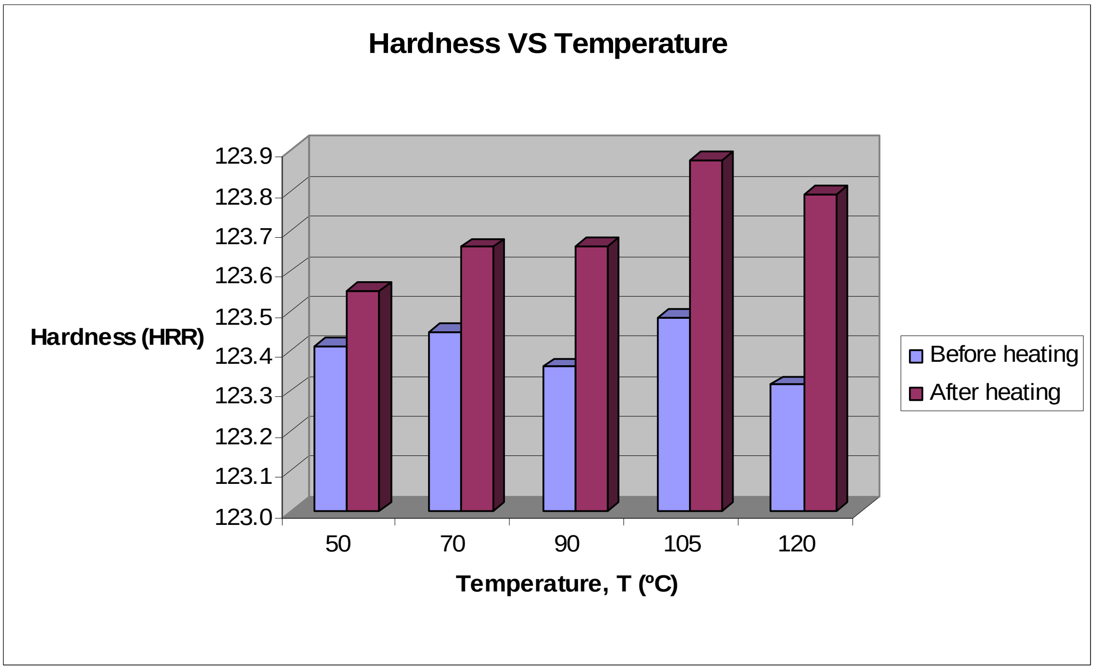


Figure 4.2: Hardness VS Temperature for Phenolic

The hardness changing percentage for both HDPE and phenolic are determined as follows:

$$\text{Hardness Changing Percentage} = [(HRR_i - HRR_f)/HRR_i] \times 100$$

HRR_i = Hardness of the sample before heating process (HRR)

HRR_f = Hardness of the sample after heating process (HRR)

The hardness changing percentage for both HDPE and phenolic at different temperatures (50, 70, 90, 105 and 120ºC) were plotted as shown in Figure 4.3.

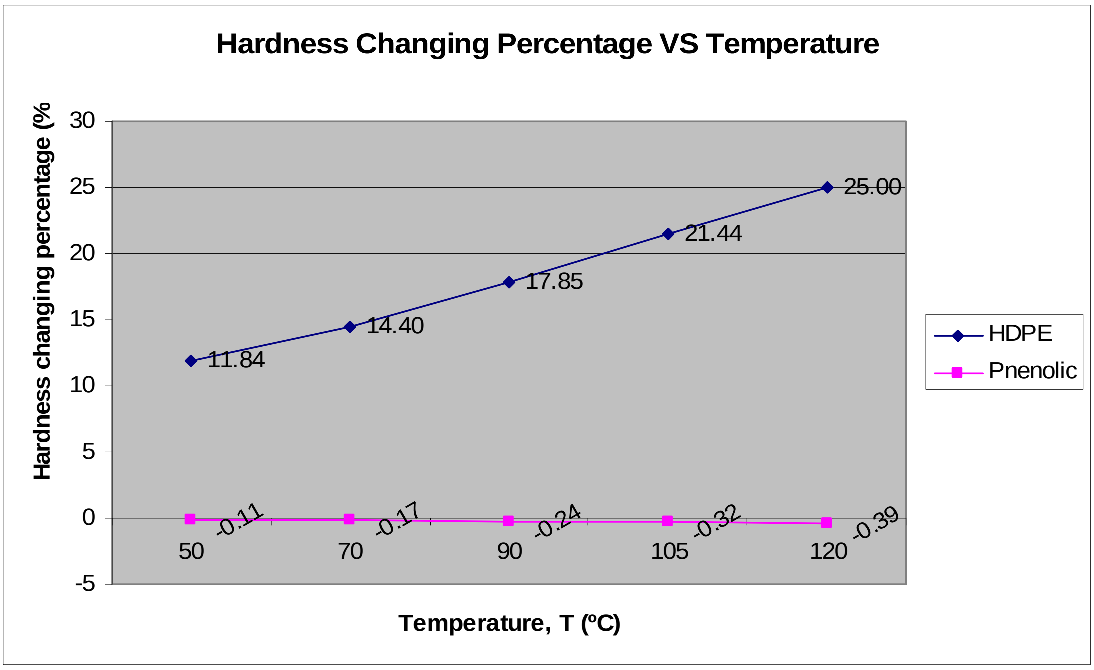


Figure 4.3: Hardness Changing Percentage VS Temperature Graph

4.1.2 Weight Loss

Weight loss percentage for HDPE and phenolic were shown in Table 4.3 and 4.4.

Table 4.3: Weight loss percentage for HDPE

Sample	Temperature, T (ºC)	Before (g)	After (g)	Weight loss (%)
A51	50	9.9974	9.9858	0.116030
A52		10.0028	9.9907	0.120966
A53		9.9951	9.9836	0.115056
A54		10.0033	9.9913	0.119960
A55		10.0000	9.9881	0.119000
A41	70	10.0031	9.9973	0.057982
A42		10.0027	9.9522	0.504864
A43		10.0020	9.9820	0.199960
A44		10.0021	9.9828	0.192959
A45		10.0011	9.9817	0.193979
A31	90	10.0022	9.9647	0.374918
A32		10.0014	9.9660	0.353950
A33		10.0034	9.9684	0.349881
A34		10.0037	9.9650	0.386857
A35		9.9969	9.9586	0.383119
A21	105	10.0036	9.9613	0.422848
A22		9.9987	9.9549	0.438057
A23		10.0003	9.9598	0.404988
A24		10.0041	9.9576	0.464809
A25		10.0050	9.9584	0.465767
A11	120	9.9956	9.9504	0.452199
A12		10.0008	9.9525	0.482961
A13		10.0027	9.9350	0.676817
A14		9.9993	9.9535	0.458032
A15		9.9995	9.9541	0.454023

Table 4.4: Weight loss percentage for Phenolic

Sample	Temperature, T (ºC)	Before (g)	After (g)	Weight loss (%)
B51	50	9.9965	9.9959	0.006002
B52		9.9988	9.9983	0.005001
B53		9.9976	9.9970	0.006001
B54		9.9992	9.9985	0.007001
B55		9.9984	9.9980	0.004001
B41	70	10.0030	10.0021	0.008997
B42		10.0032	10.0021	0.010996
B43		9.9962	9.9952	0.010004
B44		10.0015	10.0006	0.008999
B45		10.0015	10.0004	0.010998
B31	90	10.0036	10.0017	0.018993
B32		9.9954	9.9931	0.023011
B33		9.9995	9.9977	0.018001
B34		10.0041	10.0021	0.019992
B35		10.0048	10.0027	0.020990
B21	105	10.0041	10.0016	0.024990
B22		9.9958	9.9934	0.024010
B23		10.0045	10.0016	0.028987
B24		10.0050	10.0022	0.027986
B25		10.0032	10.0004	0.027991
B11	120	9.9952	9.9908	0.044021
B12		10.0038	9.9994	0.043983
B13		9.9953	9.9915	0.038018
B14		10.0020	9.9976	0.043991
B15		9.9954	9.9906	0.048022

The weight loss percentage for both HDPE and phenolic at different temperatures (50, 70, 90, 105 and 120ºC) were plotted as shown in Figure 4.4.

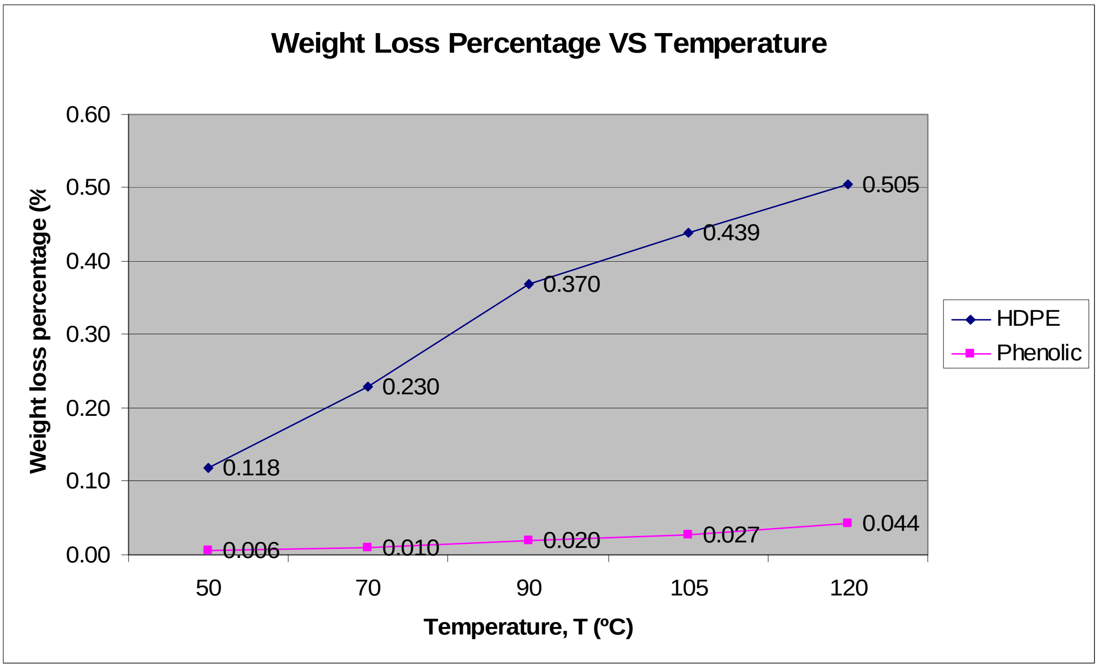


Figure 4.4: Weight Loss Percentage VS Temperature Graph

4.2 Discussion

4.2.1 Hardness

Hardness is generally referred to as a material's property that indicates resistance to surface penetration [11]. From Figure 4.1, it can be seen that the hardness of HDPE sample decreasing when undergo thermal degradation. This is due to bonding within the polymer chains is covalent, but the long coiled chains are held to one another by weak Van der Waals bond and by entanglement. When a load is applied to the polymer, the weak bonding between the chains can be overcome and the chains can rotate and slide relative to one another.

As for the phenolic, the hardness of phenolic increased when undergo thermal degradation (Refer to Figure 4.2). This is probably due to the properties of thermoset polymer which they become hard and rigid upon heating. Unlike thermoplastic polymers, this phenomenon is not lost upon cooling, which is characteristic of network molecular structures formed by the step-growth mechanism. The chemical reaction steps are enhanced by higher temperatures and are irreversible: that is, the polymerization remains upon cooling [13].

The hardness changing percentage for both HDPE and phenolic can be seen from Figure 4.3. For both HDPE and phenolic, the hardness changing percentage were increased with the temperature.

4.2.2 Weight Loss

From Figure 4.4, it can be seen that weight loss percentage for both HDPE and phenolic were increased with the temperature. But for the HDPE, the weight loss percentage and the rate of increasing were far higher than phenolic. The HDPE seem to undergone random scission process. Random scission involves the formation of a free radical at some point on the polymer backbone, producing small repeating series of oligomers usually differing in chain length by the number of carbons. If such random scission events are repeated successively in a polymer and its degradation products, the result is initially a decrease in molecular weight and ultimately weight loss [14].

CHAPTER 5

CONCLUSION

This study has attempted to determine the differences of thermoplastic and thermoset polymer when undergo thermal degradation process. From the result, it can be seen that when both HDPE and phenolic undergo thermal degradation, the hardness of HDPE will decrease while for the penolic, the hardness will increase. For the weight loss, both HDPE and phenolic has the same properties which are the percentage of their weight loss will increase when they undergo thermal degradation. These differences between the thermoplastic and thermoset polymer after undergo thermal degradation process will be useful and important to prevent or reduce the environmental pollution.

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