REUSE OF POLYETHYLENE SCRAP AS BUILDING MATERIAL FOR PLASTIC WASTE MINIMISATION

HARYANI AZAHARI

FACULTY OF ENGINEERING

UNIVERSITY OF MALAYA

KUALA LUMPUR

2013

REUSE OF POLYETHYLENE SCRAP AS BUILDING MATERIAL FOR PLASTIC WASTE MINIMISATION

HARYANI AZAHARI

RESEARCH REPORT SUBMITTED IN PARTIAL FUILFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF ENGINEERING

FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
KUALA LUMPUR

2013

UNIVERSITI MALAYA

ORIGINAL LITERARY WORK DECLARATION

Name of Candidate: Haryani Azahari I.C./Passport No.: 810508035752

Registration/Matric No.: KGJ110001

Name of Degree: Master of Engineering

Title of Project Paper/Research Report/Dissertation/Thesis ('this Work'): Reuse of Polyethylene Scrap as Building Material for Plastic Waste Minimization

Field of Study:

I do solemnly and sincerely declare that:

(1) I am the sole author/ writer of this Work;
(2) This Work is original
(3) Any use of any work in which copyright exists was done by way of fair dealing and for permitted purposes and any excerpt or extract from, or reference to or reproduction of any copyright work has been disclosed expressly and sufficiently and the title of the Work and its authorship have been acknowledged in this Work;
(4) I do not have any actual knowledge nor ought I reasonably to know that the making of this work constitutes an infringement of any copyright work;
(5) I hereby assign all and every rights in the copyright to this Work to the University of Malaya ("UM"), who henceforth shall be owner of the copyright in this work and that any reproduction or use in any form or by any means whatsoever is prohibited without the written consent of UM having been first had and obtained;
(6) I am fully aware that if in the course of making this Work I have infringed any copyright whether intentionally or otherwise, I may be subject to legal action or any other action as may be determined by UM.

Candidate's Signature Date

Subscribed and solemnly declared before,

Witness's Signature Date

Name:

Designation

ABSTRAK

Kajian ini menyelidik penggunaan bahan sisa polyethylene sebagai pengubahsuai untuk meningkatkan ciri-ciri bahan pengikat bitumen untuk tujuan pengurangan sisa. Objektif utama penyelidikan ini adalah untuk menentukan penggunaan optimum penggunaan bahan sisa dalam bahan pembinaan. Bitumen terubahsuai polyethylene dihasilkan melalui campuran dan kisaran. Kandungan polyethylene yang digunakan di dalam pengikat bitumen bervariasi dari 1, 3, 5, 7 dan 10 peratus mengikut berat. Polyethylene adalah berbentuk pellet dan panjangya 5mm. Empat jenis analisis yang terdiri daripada rheologikal, mekanikal, kimia dan morfologi permukaan dikaji untuk menentukan kesan penambahan polyethylene kepada ciri-ciri pengikat bitumen.

Kajian malalui ujian titik pelembutan, ujian penembusan, ujian kelikatan dan ujian kemuluran untuk analisis konvensional. Rheometer dinamik ricik digunakan untuk mengkaji kesan rintangan kepada perubahan bentuk dan fasa apabila dikenakan tekanan dan kesan regangan. Perubahan haba diperhatikan menggunakan penganalisis termogravimetri. Manakala morfologi permukaan dilihat menggunakan mikroskop pengimbas elektron dan mikroskop optikal.

Campuran pengikat bitumen dan polyethylene dapat menahan suhu tinggi sebelum berubah bentuk dan rintangan kepada keretakan jerih meningkat kerana ciri kelekitannya. Kajian thermogravimetri menunjukkan kestabilan haba bertambah baik berbanding pengikat bitumen asal. Bitumen yang mengandungi kandungan lebih daripada 5 peratus mengikut berat polyethylene menunjukkan fasa polimer yang berterusan bersama bitumen. Selain itu, perubahan jaringan polimer dapat dilihat melalui hasil penurunan sudut fasa.

ABSTRACT

This research focused on the application of polyethylene scrap material as modifier to enhance the properties in bitumen binder for the purpose of waste minimization. The prime objective of the study was to determine the optimum usage of scrap material in building material. Polyethylene modified bitumen was prepared by mixing and blending. The polyethylene content in the bitumen binder varied from 1, 3, 5, 7 and 10 percentage by weight. Polyethylene used is in pellet shape with 5mm of length. Four types of analysis consist of rheological, mechanical, chemical and surface morphology were conducted to study the effect of polyethylene content to bitumen binder characteristic.

The polyethylene modified binder was analyzed with softening point test, penetration test, viscosity test and ductility test for conventional studies. Dynamic shear rheometer was used to study the effect of resistance to deformation and phase difference upon applied stress and resulting strain. A thermal degradation change was observed using thermogravimetric analyzer. The surface morphology was monitored using scanning electron microscope and optical microscope.

Polyethylene modified binder was proven able to resist higher temperature before deformation and improved the resistance to fatigue cracking because of its stiffness Thermogravimetric studies showed that the thermal stability of polyethylene modified binder was improved compared to unmodified binder. Bitumen containing more than 5 percentage by weight polyethylene showed continuous polymer phase with dispersed bitumen. The transition of polymer network was observed by the decreasing of phase angle.

ACKNOWLEDGEMENT

Alhamdulillah. First and foremost, I would like to express my deepest gratitude Allah the Mightiest for granting me the strength, courage and ability to complete this study.

In particular, I would like to thank my supervisor, Dr. Ching Yern Chee, for providing me the opportunity to work in the research area of catalysis with her and for her expert guidance and mentorship. I would also like to deeply thank to Professor Dr. Mohamed Rehan, for providing me advice in the laboratory work to conduct this study and for investing time to guide me along the way. Their continuous support and encouragement has made this work possible and prepared me to accomplish my career goals. Thank you!

This thank is further extended to the mechanical laboratory's staff, chemical laboratory's staff, civil laboratory's staff and especially to all postgraduate seniors who had guided and advised me during my thesis study. I appreciated their patience and willingness to assist me.

Million thanks to my family whose unconditional love, patience and encouragement have made it possible for me to embark on this journey. Finally, I'd like to acknowledge my dear husband, Muharam, who has never wavered in his support for since we started to know each other. Without his love and support, I may not be able to achieve what I have today.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATION

ASTM	-	American Society for Testing and Materials
BS	-	British Standard
DSR	-	Dynamic Shear Rheometer
OPS	-	Oil Palm Shell
PE	-	Polyethylene
PP	-	Polypropylene
SBS	-	Styrene Butadiene Styrene
SEM	-	Electron Microscope
SHRP	-	Strategic Highway Research Program
TGA	-	Thermo Gravity Analysis
WPM	-	Waste Polymer Modifier

CHAPTER 1

INTRODUCTION

1.1 Introduction

1.1.1 Plastic and the Environment

Plastic as a product from fossil fuel contribute to emission and lastly waste materials to be disposed. It is estimated that about 100 million tonnes of plastic are produced each year (Recycling plastic). Waste production by plastic or polymer is increasing day by day and total resolve by disposal is not the prime type of choice. In Malaysia, though campaign to reduce the usage of plastic bag by the government on Saturday have been implemented (Figure 1.1), it is still a major issue as lots of other product using plastic packaging in the market are being disposed without control.

Figure 1.1 No plastic day campaign

Environmental concerns relating to the incremental rate of plastic use in consumer applications are beginning to be raised. Most obviously, municipal solid waste disposal problem is created by plastic. About one third of the plastic production used in packaging caused a high fraction of plastic in the municipal solid waste and in urban litter streams, which indirectly rose up the consumer awareness and sensitivity to the environmental impact of solid waste. (Plastics and the Environment, 2003)

Polymer recycling covers a wide range of different materials and products. These include biopolymers, synthetic polymer and natural polymers. Plastic recycling activity have started earlier in the 1970s due to the oil crisis, from then on, event by event created the need to continue the recycling activity till nowadays.

1.1.2 Polyethylene in Municipal Solid Waste

Polyethylene is commercially used by consumers worldwide. A great example of polyethylene products are plastic bag, drinking bottle and others. Polyethylene is a kind of thermoplastic which has long hydrocarbon chains. It has high density and melting point for different grade and also excellent chemical resistance.

Plastics treated as municipal waste are currently being disposed to the landfill. Plastics in landfills are found to be inert and commonly their polymer is not biodegradable which causing land fill space to be dwindling.

1.1.3 Bitumen in Construction Building

Bitumen is known as residue produced from the process of petroleum fractionation. It is widely used for road pavement comparing with another material called tar. Nowadays, many researches have been carried out to find the most suitable mixture of bitumen with other material to improve its rheological properties

By mixing the polyethylene with bitumen, we are expecting to obtain a better performance for the bitumen binder with modified polymer. Not only we can improve the bitumen binder strengths, we are also helping to reduce the amount of polymer waste by processing them into a new usable product. It’s an environmental friendly solution as we can reduce the amount of polymer waste without reducing the production of polymer itself. As we are aware that, the living style of nowadays are quite dependent to polymer products.

1.1.4 Use of Waste Material in the Construction Building

Waste material production is the disadvantage of having raping development of technologies. We cannot stop the revolution of technologies but we do have more challenges to deal with the waste produced. Recently, waste material is used for various purposes such as in road making, as fill beneath building, in brickmaking and others. (W.Gutt *et al*, 1979)

Plastic waste which comes under solid municipal waste is generated within urban areas day after day. Its production keep increasing to cater the demand of plastic consumer all around the world and at the same time creating more issues on scraping it without using up all the land that we have. Multiple ways to scrap off all the plastic waste generated such as incineration and dumping to landfill but the problem is still not totally solved. Other alternatives taken by all is to recycled it and put it back in the production chain of various industry.

Plastic waste mostly recycled back into the same product that produced the scrap, however nowadays the options are widen up. Construction industry has taken up the challenge to apply the plastic scrap in their building material to reduce their material cost and creating friendlier environment. (W.Gutt *et al*, 1979)

1.2 RESEARCH BACKROUND

1.2.1 Problem Statement

1.2.1.1 Municipal Solid Waste Management

Solid waste can be divided into three major groups, they are municipal solid waste, schedule waste and clinical waste or hospital waste which being handled by different department in the government sector. Municipal solid waste (MSW) landfill contains less toxic wastes from sources such as private homes, institutions, schools, and businesses without hazardous wastes.

Municipal solid wastes can be generated from construction, sanitation residue, waste from street and demolition. The management of schedule waste and clinical waste are better than municipal solid waste as regulation on them are stricter under Schedule Waste Regulation 2005 compared to municipal solid waste management which still struggling to solve their issues. In fact, a suitable environmental control wastes from waste collection to disposal and lastly disposal monitoring sites needed for good municipal solid waste (Chiemchaisri *et al*, 2007).

Malaysia's population has reached 28,401,017 people in 2010. (The World Bank, 2012b) With only a landmass of 329,847 square kilometers, amount of municipal solid waste generated is comparable to develop countries such as United State of America and creating problem to landfill space requirement to cater it. According to Department of Solid waste, municipal waste generated in Malaysia has reached as high as 28, 565.32 tonnes in a day. In urban areas, public health, air pollution, hazardous gas emission and odor disturbance is the common situation occurring.

Quantity of solid wastes produced annually in Malaysia cities has increased by 180% from 1991 to 2010 with the population rate increased 2.0% yearly (Figure 1.2). Most of the waste produced mainly in 3 states in the country which is Kuala Lumpur, Johor and Selangor (Nasir *et al*, 2000). The rate of waste generation in Malaysia is related to commercial activities, institutional activities and industrial activities. Economic level and economic status of the area also influenced per capita solid waste generated.

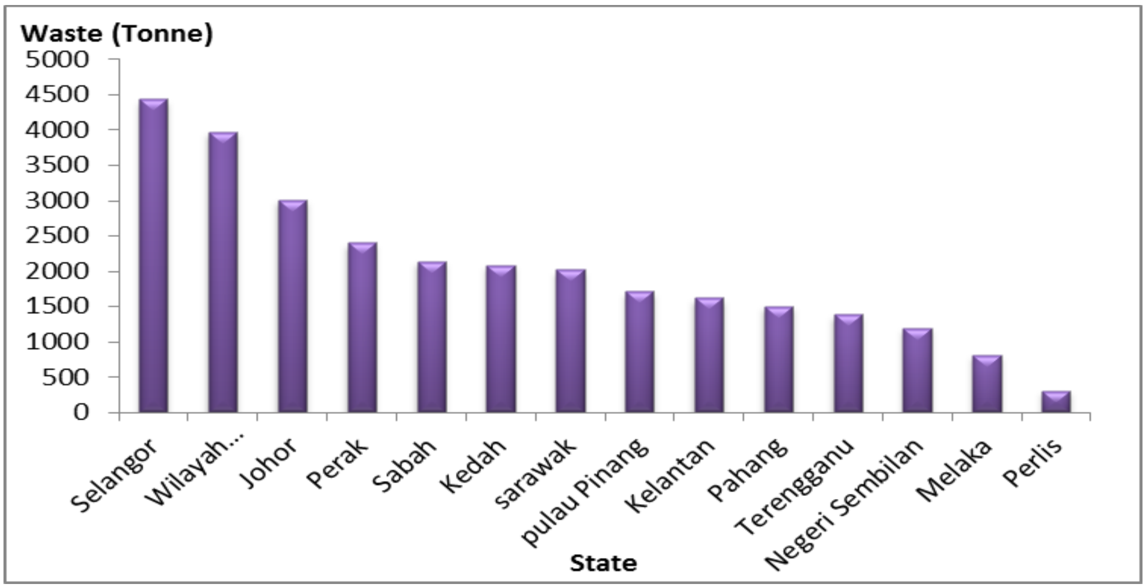


Figure 1.2 Daily solid waste disposals according to state

The national average estimated 0.711 kilogram per capita per day of waste generated for the year 1991 to 1993. (Ministry of housing and Local Government (MHLG), 2000) The numbers kept increasing to 0.8 kilogram per capita per day from 1994 to 1994 and increased to 1.5 kilogram per capita per day in year 2000. For the year 2003, it is reported the national average waste generated is 4.5 kilogram per capita per day (Ministry of housing and Local Government (MHLG), 2003).

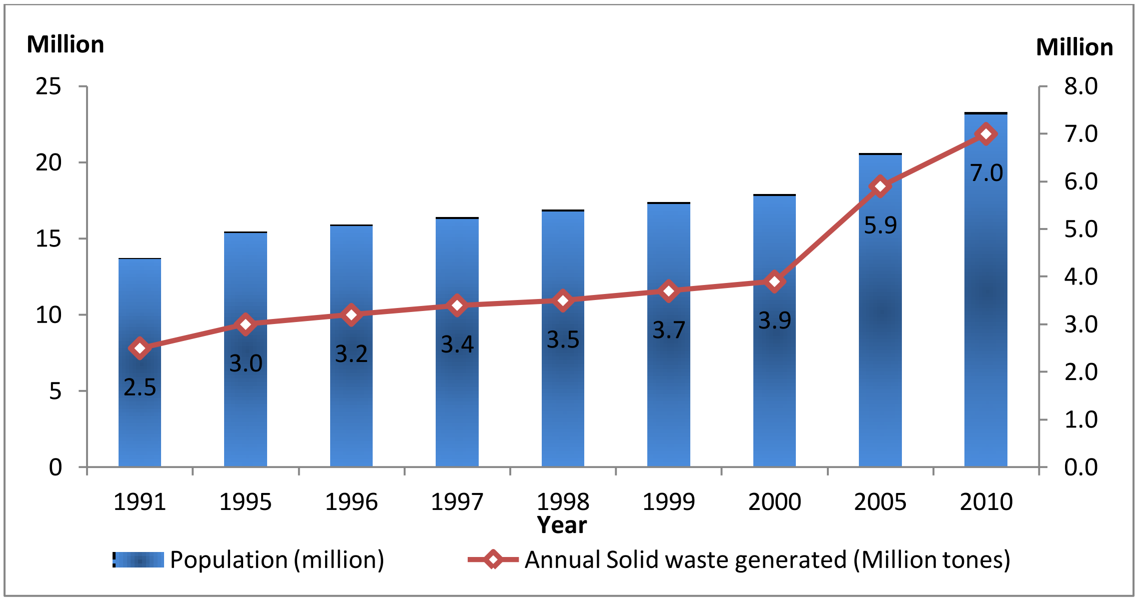


Figure 1.3 Estimation of solid waste generation in local authorities in Malaysia

Landfills are a location where residual solid waste is disposed into the ground. Open dumping and landfilling is the conventional method of disposing municipal solid waste practiced since years ago in Malaysia. With the rapid increment of population growth, economic stability and urbanization, the amount of municipal solid waste also increased. There are 166 landfill sites in Malaysia but only 5% of them are operated as sanitary landfills (Figure 1.4). Sanitary landfills are equipped with engineering facilities to dispose municipal solid waste (MSW) and operated to minimize public health and environmental impacts. While the rest are still practicing open dumping which causing more problem to the environment and human health. (Solid Waste Department of Malaysia, 2012)

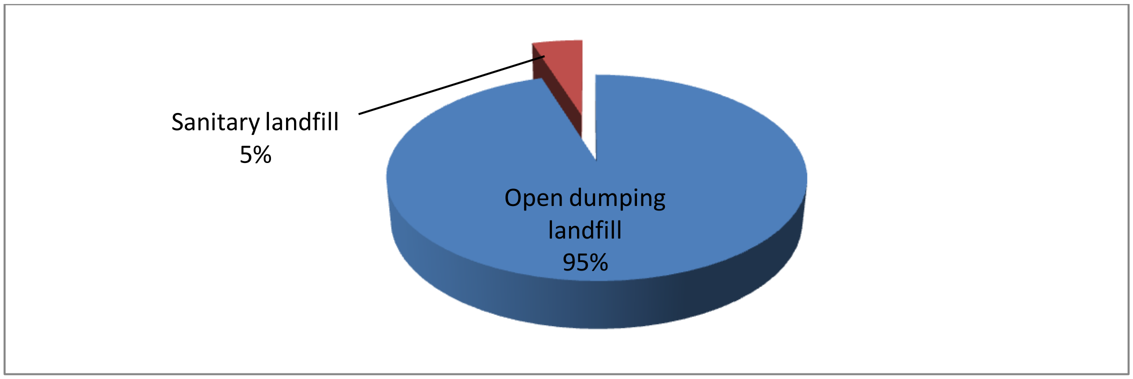


Figure 1.4 Total landfill sites in Malaysia (2011)

1.2.1.2 Waste Minimization Approach

Reduce, reuse and recycle are the three main lists in the waste management hierarchy. Malaysia as a developing country is still far behind from practicing it 100% but efforts are being done to make it happen as an approach to environmental friendly country.

With the municipal solid waste management unsolved issues, other options are taken by the government to reduce the effect to the human and environment. In 2010, the ministry has urged for recycling alternative to reduce the amount of municipal waste from landfill. The composition of solid waste across Malaysia varied from glass, steel, paper, plastic, food waste and others. In general, about 40% of the total composition can be recycled and minimize waste to be dump to the landfill (Figure 1.5) (Solid Waste Department of Malaysia, 2012).

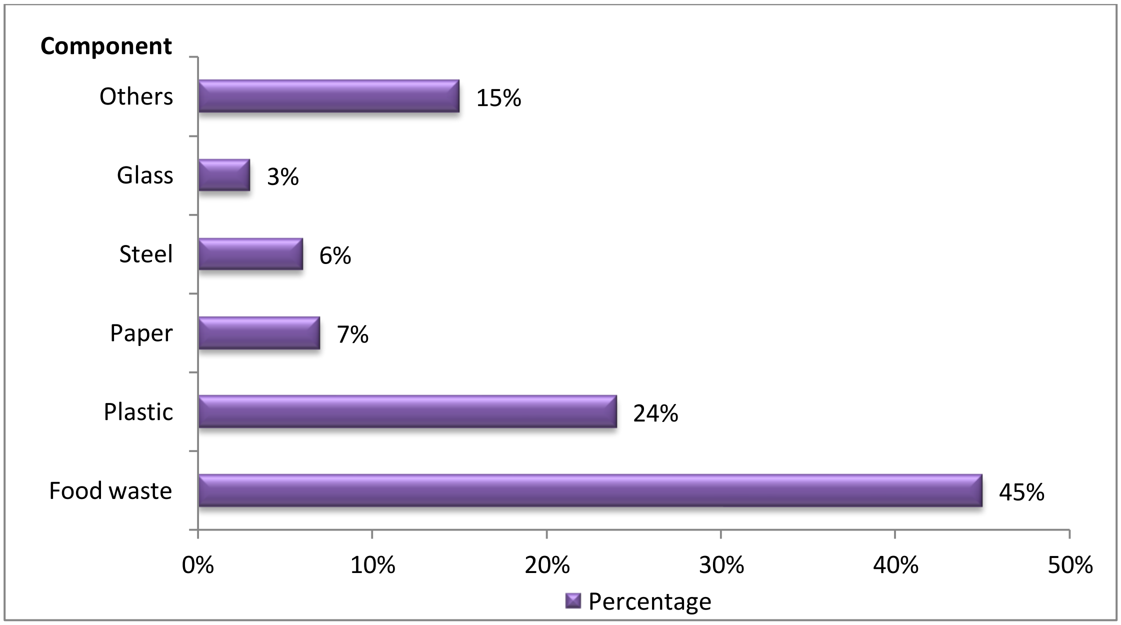


Figure 1.5 Solid waste compositions in Malaysia (2005)

Plastic waste comprises of different type of polymer such as polyethylene (plastic container), polypropylene and others. Industry sectors have played their part by recovering back their product waste and produced the same product out of them. However, the rate of producing product from waste is still not favorable by the industries as the cost for producing product from raw material is lower compared to production cost from waste material.

Recycling campaign has been carried out through out Malaysia. For example in Putrajaya, recycling has been taken seriously by the authorities to minimize waste generation. Referring to data obtained in 2011, paper waste is the highest amount of waste recycled, followed by plastic, metal and others (Figure 1.6). Putrajaya is the centralized government department for the country which explained the highest recycled waste is paper. Whereas in other state, the figures may be differ.

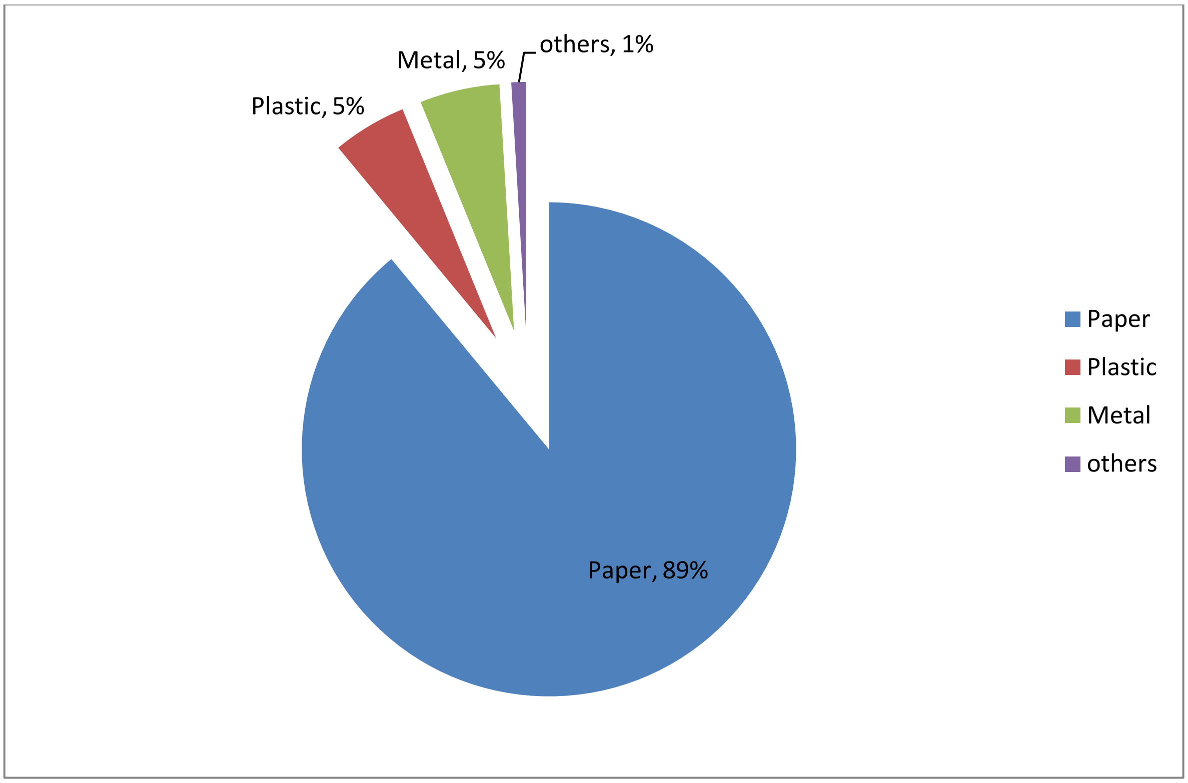


Figure 1.6 Recycle percentages according to different type of waste in Putrajaya (Feb – June 2011)

1.3 Hypothesis

1. Scrap material of polyethylene can be mix and blend with bitumen binder with composition up to 10%.
2. Modified bitumen binder with scrap material of polyethylene can enhance the characteristic of bitumen in terms of rheological, mechanical, chemical and surface morphology.
3. With the application of scrap material of polyethylene in the bitumen binder, waste minimization intention can be realized and commercialized.

1.4 Specific Objectives

The objectives of the study are:

1. Evaluate the waste minimization possibility by applying polyethylene scrap as alternative material in building construction.
2. Investigate the possibility of polyethylene scrap use as alternative modifier in bituminous mix.
3. Evaluate the characteristic of polyethylene modified bitumen.

1.5 Scope of Study

The study focuses on the characteristic of polyethylene scrap on the properties of bitumen binder which includes softening point, penetration, ductility, viscosity, dynamic shear rheology, thermo-gravity analysis and surface morphology. Five different percentage of bitumen binder containing polyethylene scrap range from 1%, 3%, 5%, 7% and 10% are prepared by mixing and blending. Comparison of experimental result between pure bitumen and polymer modified binder are conducted.

CHAPTER 2

LITERATURE REVIEW

2.1 Polyethylene Scrap

Polyethylene is commercially used by consumers worldwide. Polyethylene is a kind of thermoplastic which has long hydrocarbon chains. It has high density and melting point for different grade and also excellent chemical resistance. Polyethylene can be divided into High Density Polyethylene (HDPE) and Low Density Polyethylene (LDPE). A great example of polyethylene products are plastic bag, bread packaging, toys and milk bottles.

Polyethylene scrap or recycled Polyethylene has consistent Melting Flow Index (MFI) and density which give clean natural-colored product. It also retains the same rheological properties as the original resin as it does not treated under thermal degradation during recycling.

Recycled polyethylene may be reprocessed by different method of mechanical and chemical process. Chemically, the polymer can undergo dissolution–reprecipitation technique (D. S. Achilias *et al*, 2009) and mechanically the polymer can be shredded and processed into new products.

2.2 Bitumen

Definition

According to BS3690 Part 1 1989, bitumen is defines as "a viscous liquid or a solid consisting essentially of hydrocarbons and their derivatives, which is soluble in trichloroethylene and is substantially non-volatile and softens gradually when heated. It is black or brown in color and possesses waterproofing and adhesive property. It is obtained by refinery processes from petroleum and is also found as a natural deposit or as a component of naturally occurring asphalt in which it is associated with mineral matter." (Bitumen Shell Book)

In the study of influence of chemical composition on physical characteristic of bitumen by Oyekunle *et al*, (2007) stated that the bitumen of low penetration values has high asphalt content and the softening point value will increase with the increase of asphalt content. Its colloidal stability will decrease when the asphalt content increased and the ductility values will also increase with the increment of resin.

Bitumen is widely used for road pavement comparing with another material called tar. Nowadays, much research has been carried out to find the most suitable mixture of bitumen with other material to improve its rheological properties.

2.2.1 Health, Safety and Environment Aspect of Bitumen

Bitumen does not cause any health or environment hazard in solid form but during its application, storage, transportation and use of it does emits fumes which is carcinogenic to human health. When bitumen is heated up to temperature of 150°C, it started to give of emissions of hydrocarbon which also includes nitrogen, sulfur and oxygen as it in poly aromatic group (Sippy *et al*, 2010), these gases also possess health issues to human health.

Awareness of improving the safety and health procedures in the workplace applies in the construction industry where bitumen is majorly in used.

2.3 Polymer Modified Bitumen

By mixing the polyethylene with bitumen, we are expecting to obtain a better performance for the bitumen binder with modified polymer. Not only we can improve the bitumen binder strengths, we are also helping to reduce the amount of polymer waste by processing them into a new usable product.

2.4 Overview of Previous Study

A comparative analysis was conducted between pure and recycled polymer on bitumen modification by F.J. Navarro *et al*, (2010). It concluded different recycled polymers (EVA, Low Density Polyethylene/EVA blend and rubber crumb) improved binder rheological properties at high temperature. According to this study, 5% weight of EVA/LDPE gave the highest linear viscoelasticity and recycled polymers are unstable at high temperature storage.

M. Garcia-Morales *et al*, (2005) have conducted rheological studies for four different types of waste polymers which are crumb tire rubber, ABS, EVA and lastly EVA/LDPE blend as bitumen modifying agent. Based on his result, by mixing 3.5 weight% of EVA/LDPE and 3.5 weight% crumb rubber gave better characteristic of the bitumen in different range of temperature. As for blending of EVA and LDPE, they displayed good result in high in-service temperatures.

A.I. Al-Hadidy *et al*, (2008) used Low Density Polyethylene (LDPE) as a modifier for asphalt paving materials. It was observed that up to 6% of polymer addition kept the ductility value at a minimum range of ASTM. The modified binder improved the shear resistance in medium to high temperature and resistance to deformation. Marshall Test, indirect tensile strength and flexural strength were conducted too and their result showed improvement on the characteristic of the binder.

Plastic waste containing Polyethylene Terephthalate (PET) was studied in the bituminous binder rheological evaluation by Abdel Aziz Mahrez *et al*, (2010). Test conducted included penetration test, softening point test, viscosity test and dynamic shear rheometer test. The result showed that the value of softening point and viscosity increased for recycled PET. Though it lowed the penetration values but better viscoelastic properties was achieved for the modified binder. Modified binder with PET also improved its rutting resistance than original bitumen.

Recycled polyethylene modified bitumen using 150/200 grade penetration bitumen studies by Cristina Fuentes-Aude´n *et al*, (2008) focused on the thermal and mechanical properties of the binder. Referring to the result, low concentration of polyethylene which is from 0-5% can be considered for road paving whereas higher concentration of polyethylene addition to the bitumen is more suitable for building construction such as membrane roofing. Conclusion from these studies is based on the increment value of storage, loss moduli and also viscosity. The modified polymer binder also gave better resistance to permanent deformation compared to pure bitumen itself.

Zahra Niloofar Kalantar *et al*, (2012) have reviewed studies of using pure polymer and waste polymer in road pavement application. In her reviews, she stated that different kind of original and waste polymer types can improve the pavement lifespan when the right composition is chosen. Polymers included in her reviews are Polyethylene, Polypropylene, PVC, Styrene–butadiene block copolymer (SBS) and Styrene–isoprene block copolymer (SIS).

In studies conducted by Yue Huang *et al*, (2007), recycled plastic claimed to substitute part of aggregates or act as binder modifier. By replacing about 30% of aggregates with Low Density Polyethylene, the mix density reduced to 16% and showed 250% increment in Marshall Stability. Overall, the substitution of aggregates with low density polyethylene improved the water resistance, rutting, indirect tensile strength and Marshall Stability.

Studies on waste polymer with combination of nitrile rubber and polyethylene as modifier in bitumen binder were conducted by Sangita *et al*, (2011). Various evaluations on mechanical properties (Marshall Stability, Marshall quotient, resilient modulus and permanent deformation) of the modified binder been carried out and concluded at 8% content of the modifier improved the mechanical properties of the binder. Thermal degradation behavior also studied at showed that the waste polymer modifier stable up to 230°C and degradation will not occur during hot aggregate blending process (Figure 2.1).

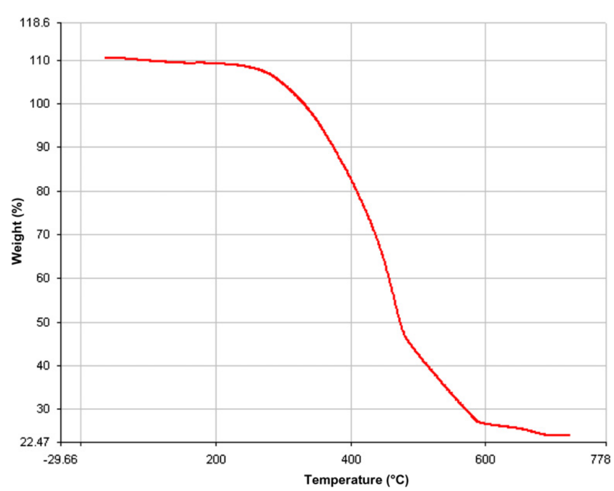


Figure 2.1 TGA curve for waste polymer modifier (WPM)

CHAPTER 3

METHODOLOGY

3.1 Material and Method

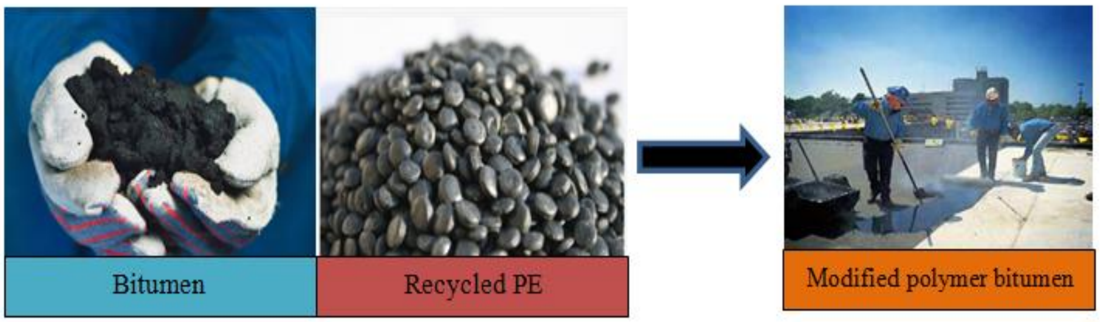


Figure 3.1 Material of research

3.1.1 Polyethylene Scrap

Recycled or scrap Polyethylene in pellet form of about 5mm in length is obtained from the polymer manufacturer, The Titan Company. The plant produced products from polymer and also ran a recycled plant for polymers. The scrap Polyethylene used has a melting point ranging from 105 to 115 °C.

3.1.2 Bitumen

In this study, bitumen with penetration grade of 80/100 is used as the binder. The conformance of the bitumen grade was done referring to the Manual on Pavement Design for penetration grade 80/100 which includes penetration test, softening point test, ductility test and viscosity test (Table 1).

Table 3.1 Bitumen basic rheological characteristic

Test	Standard method	Standard specification	Average
Penetration at 25°C (1/100cm)	ASTM D5	80-100	98
Softening point	ASTM D36	45< x<52	50
Ductility at 25°C (cm)	ASTM D113	< 100	99
Viscosity at 135°C (MPas)	ASTM D4402	321	320

3.2 Preparation of Polymer Modified Bitumen

Polyethylene (PE) scrap in pellet shape is used to mix with the bitumen. In this study, five different concentration of polyethylene which range from 1% to 10% by weight were mixed using high shear mixer at RPM of 1000 – 2000 (Table 3.2). Before mixing, the bitumen is heated at 100°C for 1 hour to ease up the mixing process with the polymer. The temperature during the mixing using high speed shear mixer is monitored to be in range of 140°C – 160°C using thermometer.

Table 3.2 Bitumen and polyethylene mass

Bitumen (Gram)	Polyethylene	PE (Gram)	Mixing Time
1789.00	1%	17.89	45 min
2543.10	3%	76.30	50 min
1924.40	5%	96.20	46 min
2534.50	7%	177.40	55 min
2453.10	10%	245.00	65 min

3.3 Characterization Test Method

3.3.1 Rheological Analysis

Rheology by definition studied the flow of matter whether it is physically in liquid, soft solid or solid condition. The analysis can be applied to various substances with complex molecular structure such as polymers, silicates, blood and others.

3.3.1.1 Softening Point

Softening point test is conducted to measure the consistency of bitumen. According to ASTM D36, a steel ball weighing 3.5g is located on bitumen cast in a brass ring, immersed in water with temperature of 25°C and heat is applied to it until the bitumen and steel ball touch a base plate 25mm below the ring. The mean temperature is written after duplicate test were conducted showing the degree of it softening point.

3.3.1.2 Penetration

Penetration test is also a measurement of consistency for bitumen. Higher value of penetration shows softer consistency. Penetrometer is used to conduct penetration test (Figure 3.2). Sample prepared in 100ml sized tin is immersed in 25°C temperature of water. Crushed ice is used to maintain the temperature and thermometer is used to monitor it. The needle penetrated into sample and reading obtained after 5 second is multiplied to ten to have in it penetration unit because the depth of penetration is measured in unit of 0.1mm (Figure 3.3).

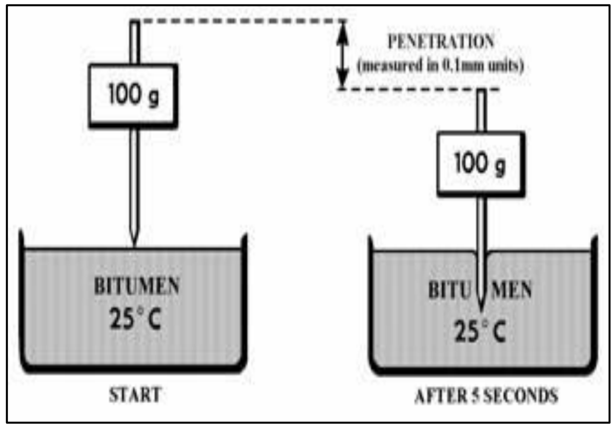


Figure 3.2 Penetrometer Figure 3.3 Penetration test

3.3.1.3 Viscosity

Viscosity measures the resistance of fluid to flow. Liquid with higher viscosity is less ease for its movement to flow. Brookfield viscometer is used in ASTM D4402 to determine viscosity for bitumen. A range of temperature is conducted during the test. For this study, temperature at 135°C is specified to measure its viscosity.

3.3.1.4 Ductility

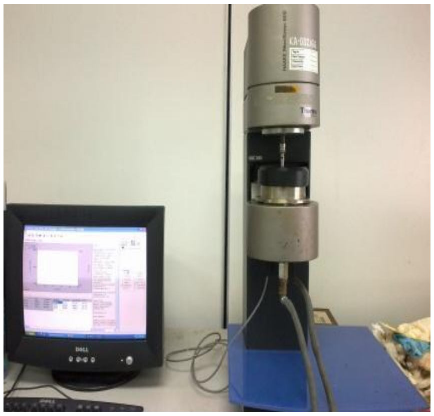
Ductility is the ability of a material to stretch under tensile stress. Conventional Ductility meter equipment is used to carry out this analysis. Samples are poured into ductility mold and the test in carried out in controlled temperature of 25°C. Readings were taken when the samples were stretched till it broke off (Figure 3.4).

Figure 3.4 Ductility test

3.3.2 Mechanical Analysis

3.3.2.1 Dynamic Shear Rheometer

Dynamic Shear Rheometer (DSR) equipment is used to find out the rheological properties of bitumen binders (Figure 3.5). Dynamic frequency test and viscous flow measurement were performed in a controlled stress using the equipment. Samples were prepared using a G compressed tool to have it surface of the samples flatten and left for 24 hours to harden it. Then the samples were cut into round shape with 3cm diameter before it was analyzed at temperature of 76°C (Figure 3.6) (Nur Izzi Md. Yusoff *et al*, 2011).



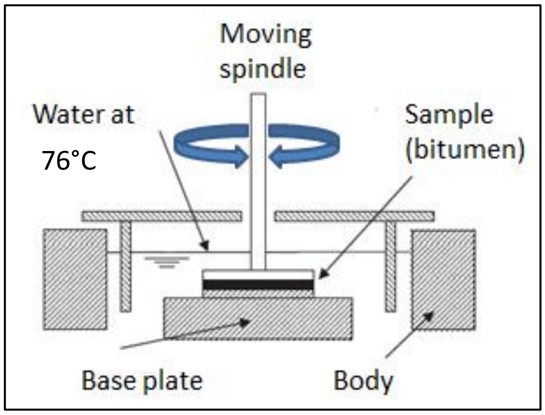


Figure 3.5 DSR

Figure 3.6 DSR mechanisms

3.3.3 Chemical Analysis

3.3.3.1 Thermogravity Analysis (TGA)

Thermo-gravimetric (TGA) measures the values of heat loss, heat gained and weight loss on heating, cooling, and others (Figure 3.7). Thermo-gravimetric analysis uses heat to create force reactions and physical changes in material. Mettler Toledo Themo-gravimetry equipment (TGA/S TDA) serve the purpose for this study.

Figure 3.7 TGA equipment

3.3.4 Surface Morphology

3.3.4.1 Scanning Electron Microscope (SEM)

Images of sample by scanning with beams of electron are produced by scanning electron microscope (Figure 3.8). It is operated under high vacuum which only can be used on dry sample without any water content. The polyethylene scrap's morphology is analyzed using SEM under high vacuum condition.

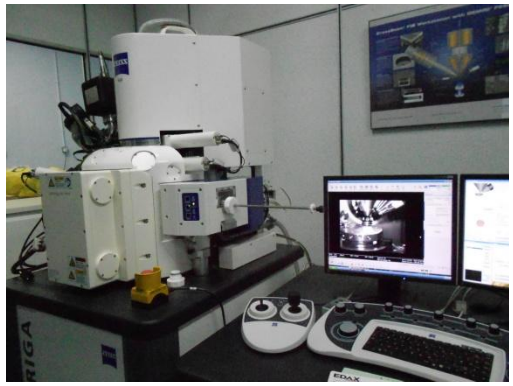


Figure 3.8 SEM equipment

3.3.4.2 Optical Microscope

Optical microscope is used to view magnified images of sample under visible light (Figure 3.9). With high resolution, the morphology of sample can be observed and analyzed. A standard light optical microscope Olympus BX61 is used for this purpose. Samples were put on standard Premium microscope slide by Fischer Finest with the size of (76x26mm). The sample was heated up to 75°C for 5 minutes on a ceramic hot plate to obtain very flat surface of sample.

Figure 3.9 Optical microscope

CHAPTER 4

RESULT AND DISCUSSION

4.1 Characteristic of Scrap Polymer Modified Bitumen

4.1.1 Rheological Analysis

4.1.1.1 Softening Point

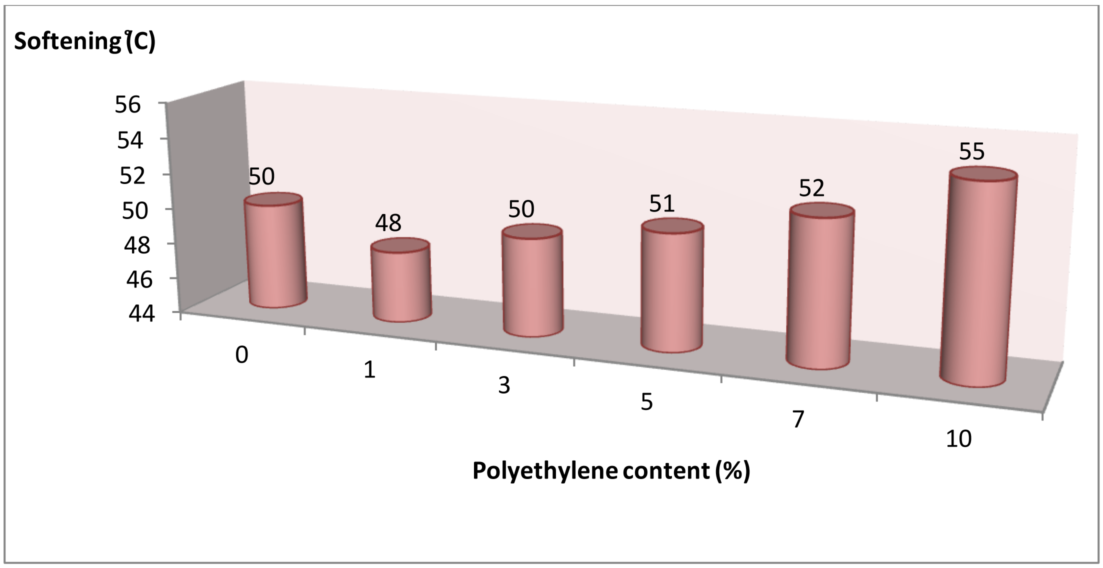


Figure 4.1 Effect of polyethylene composition to softening of bitumen

The result in Figure 4.1 showed that softening point for polyethylene modified bitumen is as about the same as base bitumen. This is because the internal structure formed by polymer which is thermodynamically stable, do not give any affect to softening point (Noor Zainab Habib *et al*, 2010).

The softening temperatures slightly increased indicating the better the binder is after mixing with polyethylene. With the addition of polyethylene to the binder, it can resist higher temperature before deformation.

4.1.1.2 Penetration Test

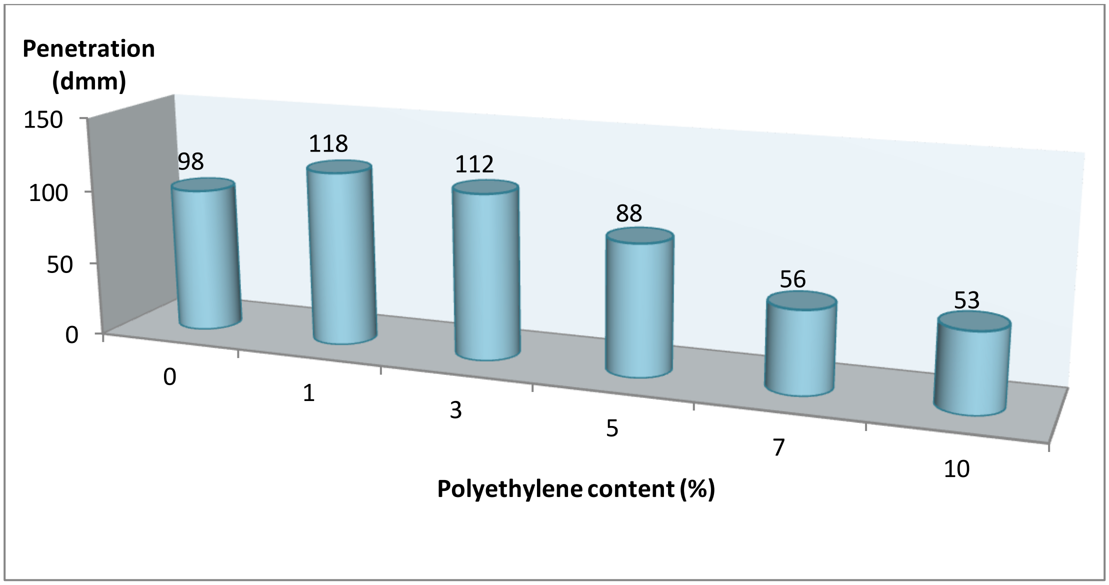


Figure 4.2 Effect of polyethylene composition to penetration of bitumen

Penetration test measurement obtained is described in Figure 4.2. A higher penetration value indicates lower consistency of the polymer modified bitumen. Based on result obtained, with the increment of polyethylene addition, their consistency kept decreasing on average 17% reduction. When consistency is reduced, it is less hard but it improved the resistance to fatigue cracking because of its stiffness.

Pure bitumen used in this study has the value of penetration at 98. Referring to the result, polyethylene addition at 5 wt. % concentration has the closest value to it. So, it can be chosen to have 5 wt. % addition of polymer to the bitumen binder to achieve higher resistance to fatigue cracking with consistency.

4.1.1.3 Viscosity

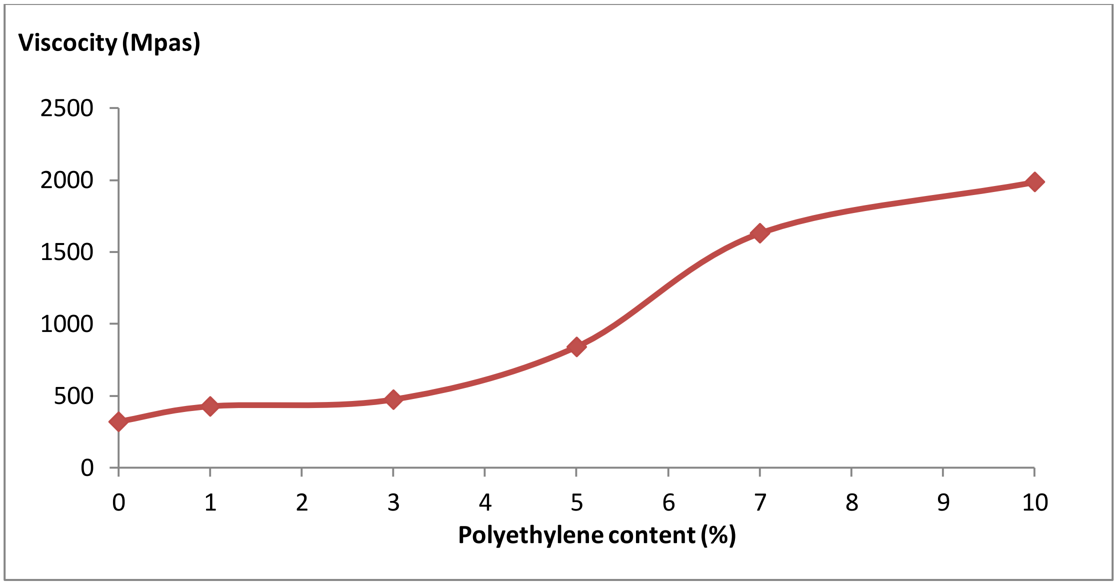


Figure 4.3 Effect of polyethylene composition to viscosity of bitumen

Viscosity test is used to measure the resistance to flow and its internal friction. According to Abdel Aziz Mahrez, (2010), the viscosity of asphalt binder at high manufacturing and construction temperatures is generally above 135°C due to three factors which are ability to pump, ability to mix and workability.

Figure 4.3 showed that the viscosity of polymer modified binder increased as the polyethylene addition increased. Structural changes happen when viscosity increased resulting higher stiffness. It is stated in ASTM D3673 that bitumen binder is practicable at value below 3000mPas, thus polyethylene modified bitumen does satisfied the criteria as the highest viscosity value is 1987mPas for 10 wt. %.

4.1.1.4 Ductility

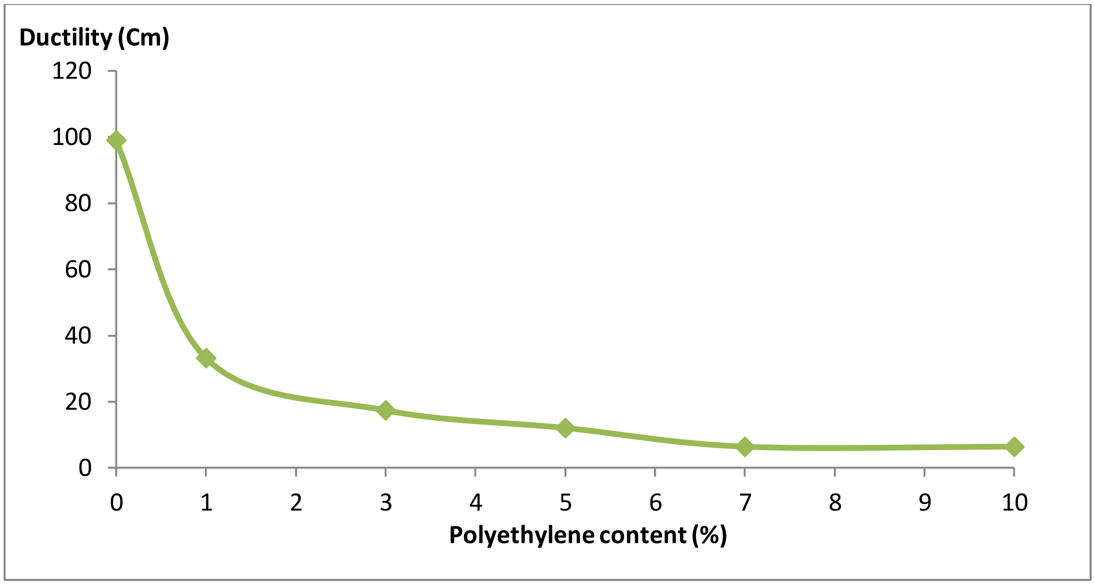


Figure 4.4 Effect of polyethylene composition to ductility of bitumen

Ductility test used to evaluate the anti-cracking performance of asphalt at low temperature (Changqing Fang *et al*, 2011). Referring to the result shown in Figure 4.4, the ductility values decreased as the polyethylene addition increased to the binder. Generally, bitumen with 80/100 penetration grade has the value of ductility more than 100cm.

As the polyethylene modified bitumen get harder and stiffens, the reduction of ductility values is predictable. Addition of polyethylene to viscous bitumen tends to reduce the ductile characteristic of the material. According to ASTM D113, the ductility value is less than 100cm, thus polyethylene modified bitumen from 1 wt. % to 10 wt. % addition fulfill the requirement and can be applied for pavement usage.

4.1.2 Mechanical Analysis

4.1.2.1 Dynamic Shear Rheology (DSR)

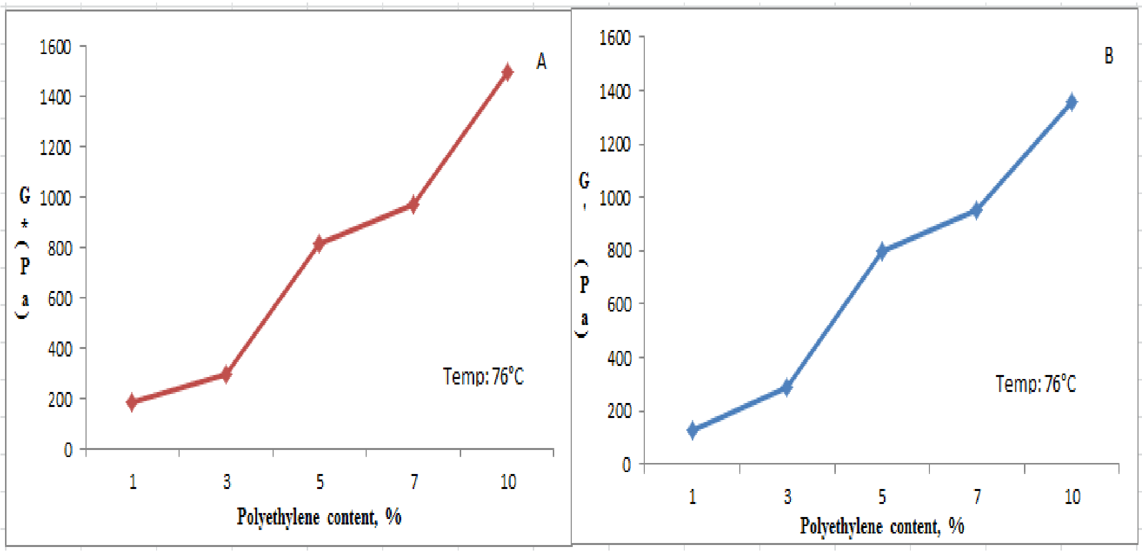


Figure 4.5 Effect of polyethylene composition to complex shear modulus, G* and elastic modulus, G' of bitumen

Mechanical characteristic of scrap polymer modified bitumen has been carried out at temperature of 76°C. The complex shear modulus (G*) is defined as the ratio of the peak stress to the peak strain which measure the overall resistance to deformation of a material when repeatedly sheared.

With the increment of scrap polyethylene addition to the bitumen, the elastic modulus, G' showed significant increments too. At 1 wt. % concentration of polymer bitumen binder, the value of elastic modulus started from 125 Pa increased to 1574 Pa at 10 wt. % concentration of polymer addition to bitumen (Figure 4.5B).

With lower elastic modulus and higher tan δ, higher energy will be released and with impact of traffic loadings, thermal cracking will occurred (M. García-Morales *et al*, 2005). According to Shell bitumen handbook, thermal cracking will occur when the bitumen becomes too stiff to withstand the thermally induced stress and it is related to the coefficient of thermal expansion and the relaxation characteristic of the mixture.

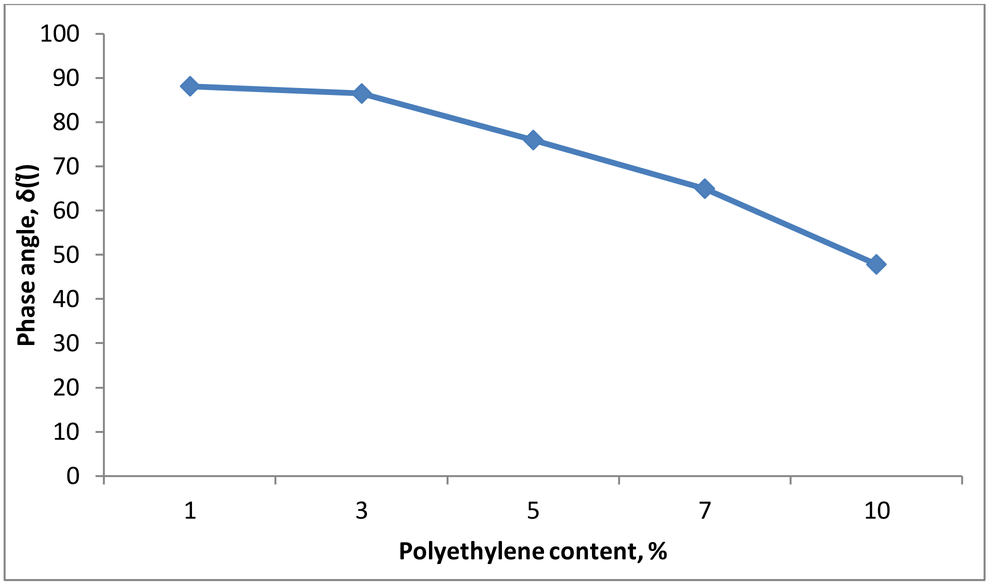


Figure 4.6 Effect of polyethylene composition to phase angle of bitumen

Phase angle (δ) is defined as the phase difference between the applied stress and the resulting strain. Figure 4.76 illustrate the phase angle of polyethylene modified bitumen decreased as the polyethylene content increased.

At 1 wt. % concentration of the polyethylene, the phase angle value is 88° C and the value kept decreased to 48° C at 10 wt. % of polymer concentration. The value of phase angle slightly decreased from 1 wt. % to 5 wt. % polymer content, this transition indicates polymer network in the mixture (Abdel Aziz Mahrez, 2010)

4.1.3 Chemical Analysis

4.1.3.1 Thermogravity Analysis

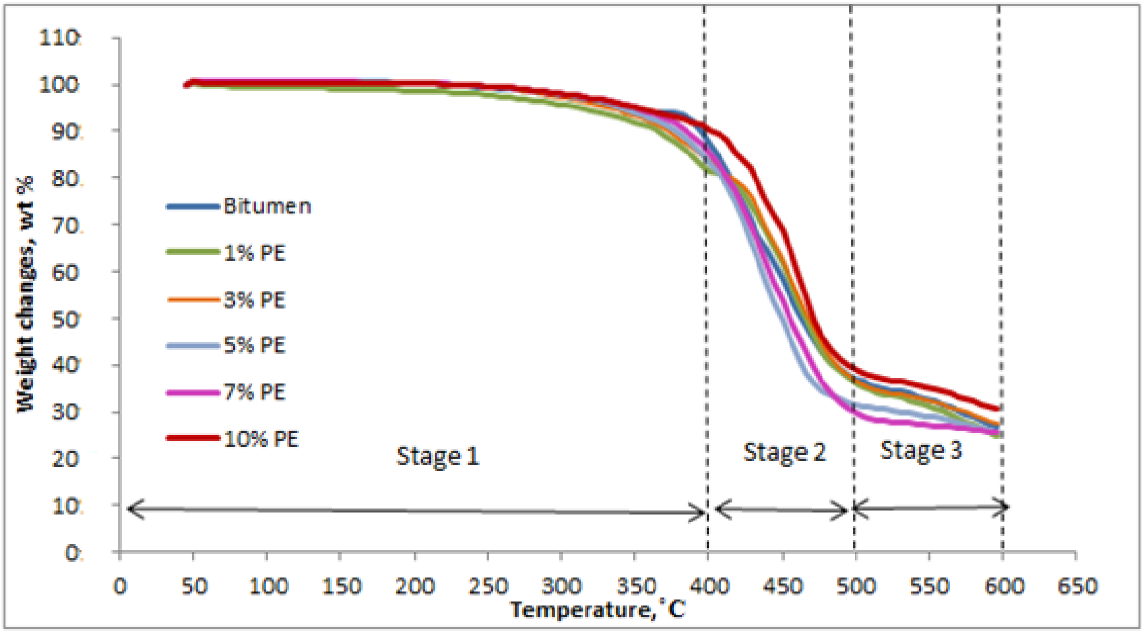


Figure 4.7 Effect of polyethylene composition to thermogravity distribution of bitumen

Thermogravimetric Analysis (TGA) measures the amount and rate of change in the weight of a material as a function of temperature or time in a controlled atmosphere. Thermal degradation behavior of polyethylene modified bitumen and base bitumen is reflected in Figure 4.7. Clearly, 3 different stages of distribution can be observed.

At stage 1, weight changes for all the tested material is less obvious indicating slow decomposition has occurred. Apparent slope curve is illustrated at stage 2 where temperature is between 400°C to 500°C. Mass loss of the binder was mainly due to the volatilization of light asphalt components such as saturates and aromatics and the decompositions of asphaltenes (Feng Z *et al*, 2011).

For stage 3, weight loss is less drastic as in stage 2. Thermal stability of neat and modified bitumen binders is one of the most important properties for production, application, and service (M. Naskar *et al*, 2012). Averagely, polyethylene addition to the bitumen binder from 1 to 10wt. % have thermal stability until 400°C. Modified bitumen with 5 wt. % plastic was found to have the highest thermal stability compared to other binders investigated (M. Naskar *et al*, 2010). It can be said that, polyethylene modified bitumen is safe to use as up to 400°C before it lose its characteristic.

4.1.4 Surface morphology

4.1.4.1 Polyethylene Scrap

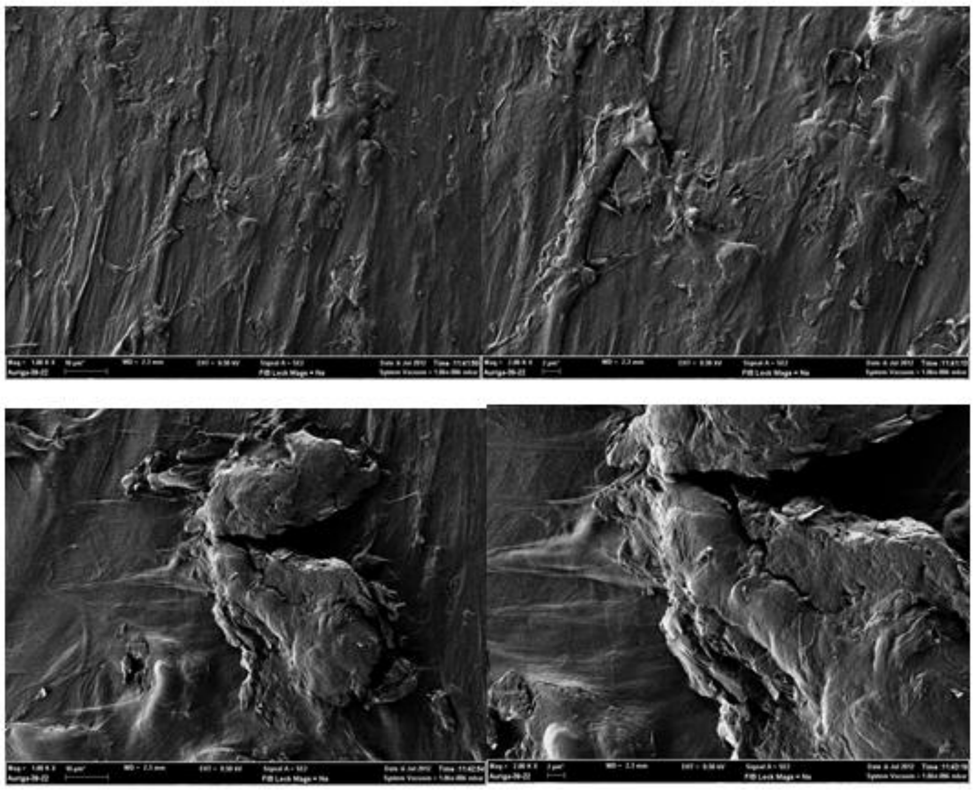


Figure 4.8 Images of scrap polyethylene sample before modification to bitumen

The microstructure of polyethylene scrap were observed by SEM. The images of scrap polyethylene with 1kx to 10kx magnification are shown in Figure 4.8.

Though the polymer already undergone chemical process and mechanical process, its characteristic still remain unchanged like the virgin polymer. Polyethylene is mostly affected under stress and deformation as sliding of chain with respect to engtanglements occures at the nodes (Drozdov Aleksey *et al*, 2003).

4.1.4.2 Bitumen 80/100 grade

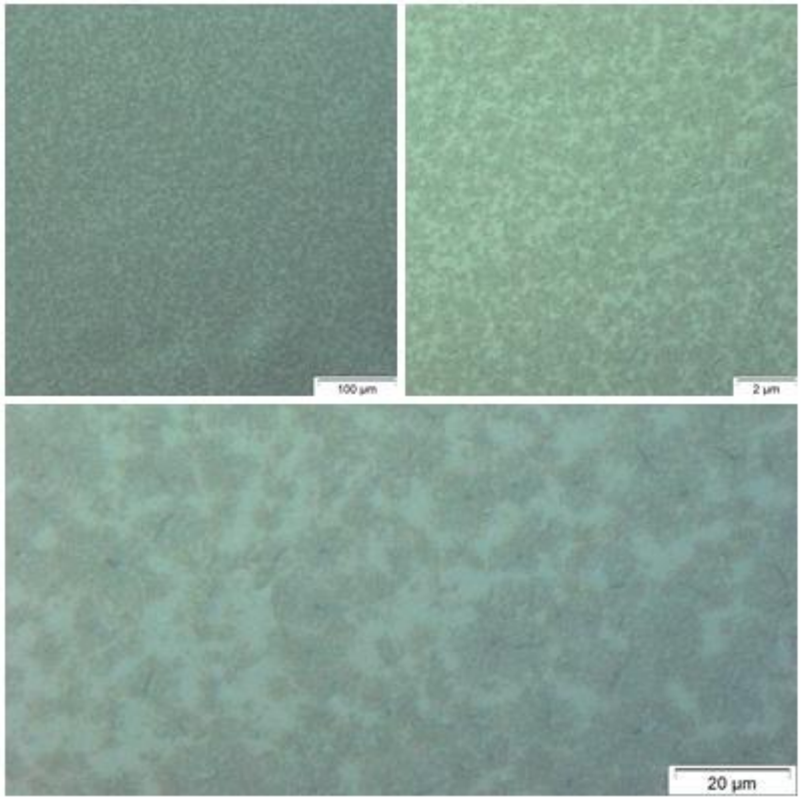


Figure 4.9 Images of bitumen at 2x, 20x and 100x magnification

Natural bitumen not only contains hydrogen and carbon, it also contains sulfur, oxygen, nitrogen and heavy metals such as nickel, vanadium, iron, and copper. Figure 4.9 indicates the images of the bitumen captured using optical microscope 2x, 20x and 100x magnification.

Before adding polyethylene to the binder, a continuous phase of bitumen can be observed clearly. After mixing with polyethylene applied with heat, the texture and the phase of the bitumen changed. The composition and temperature of bitumen strongly influence the mechanical properties and microstructure of bitumen (M. Garcı´a-Morales *et al*, 2005).

4.1.4.3 Polymer Modified Bitumen

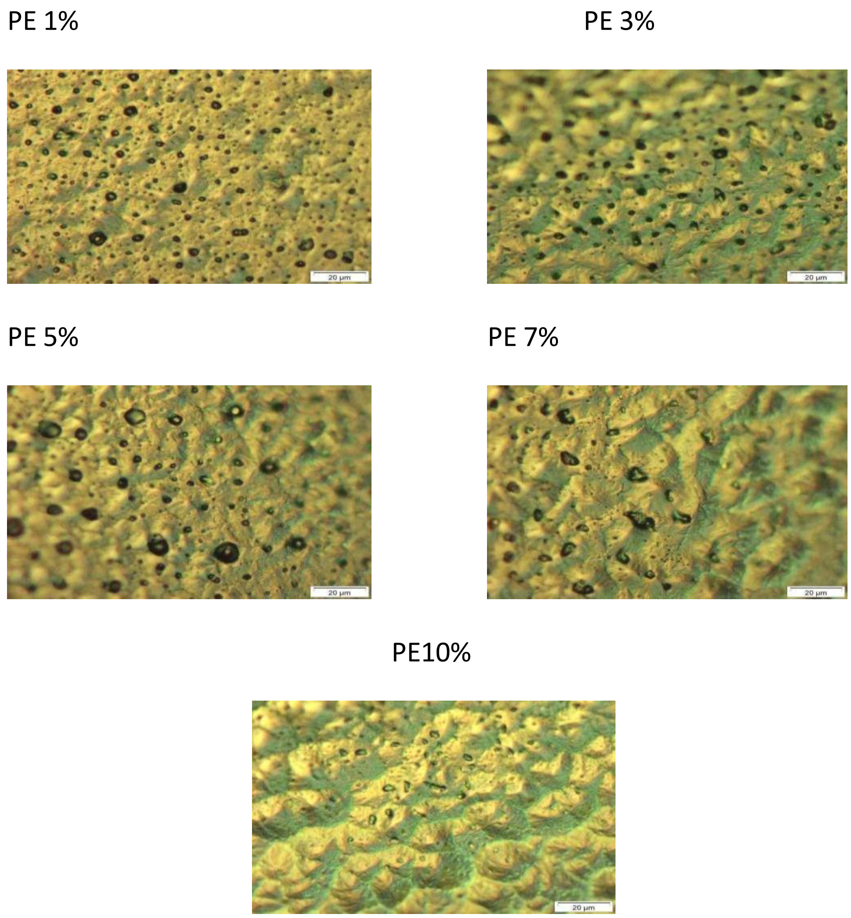


Figure 4.10 Images of polyethylene modified bitumen with 50x magnification

The mutual effect of polymer and bitumen can be resulted in the morphology as it is affected by the bitumen content and polymer content itself (Xiahu Lu *et al*, 1999). Optical microscope has been used to investigate the state of polymer dispersion within the base of bitumen.

Images shown in Figure 4.10 referred as polyethylene modified bitumen at different percentage from 1% to 10% of mass addition with 50x magnification. At 1% and 3% addition of the polymer, it is seen to have homogeneous texture with the bitumen showing no significant variation in morphology. However, as the addition increased, the texture began to change. At polymer concentration more than 5wt. %, a continuous polymer phase with dispersed bitumen phase is observed. Different bitumen morphologies can be yield from higher polymer concentration, showing a narrow dispersion of bitumen droplets in a polymer-rich continuous phase (Cristina Fuentes-Aude´ n *et al*, 2008)

Most common problems associated with bitumen binder are deformation at high temperature (rutting), thermal cracking at low temperature, load-associated fatigue cracking and ageing. Improvement on the bitumen binder with polymers is believed to overcome all the problems related to it.

Addition of polymer to bitumen improves the mechanical properties of the composite by diminishing thermal susceptibility and rutting. Since its effective glass transition temperature decrease, it increased the resistance for cracking at low temperature (Garcı´a-Morales *et al*. 2004a). With the increase of softening point and decrease in penetration values, the viscosity of blend enhanced rapidly and improves deformation resistance (Hadidy Al *et al*, 2009). The use of modified bitumen is economically and financially viable. Modified bitumen requires less thickness, longer life and less maintenance cost (Swapan Kumar Bagui *et al*, 2012)

4.2 Waste Minimization

4.2.1 Challenges of Implementation

Waste minimization comprises of the words reduce, reuse and recycle, in three simple words, the actions or activities to achieve its objectives is far more complex than the words itself. As in Malaysia itself, the government is still struggling on the waste minimization concept to be accepted by all. Though there are organizations that already started their waste minimization activities years ago, but the quantity is still small and this does not solve the waste management issues in Malaysia.

As shown in Figure 4.11, the process flow of plastic waste management started with separation or purification process then followed by recycling process before the plastic can be produced again as plastic or non-plastic product. In the recycling step, the waste plastic may undergo thermal reprocessing process, chemical modification or fillers process.

Another option for the plastic waste is to be disposed to landfill or incinerator. When the waste is processed in the incinerator, pollution gas emissions occurred but energy can be produced from it. This scenario is ironic as our intention is to minimize waste but we also produce another environmental issue when we are solving other issue. Dumping the plastic waste to the landfill also creates environmental issues as plastic does not decompose in short duration and the quantity kept increasing crowding all the 166 landfills in Malaysia

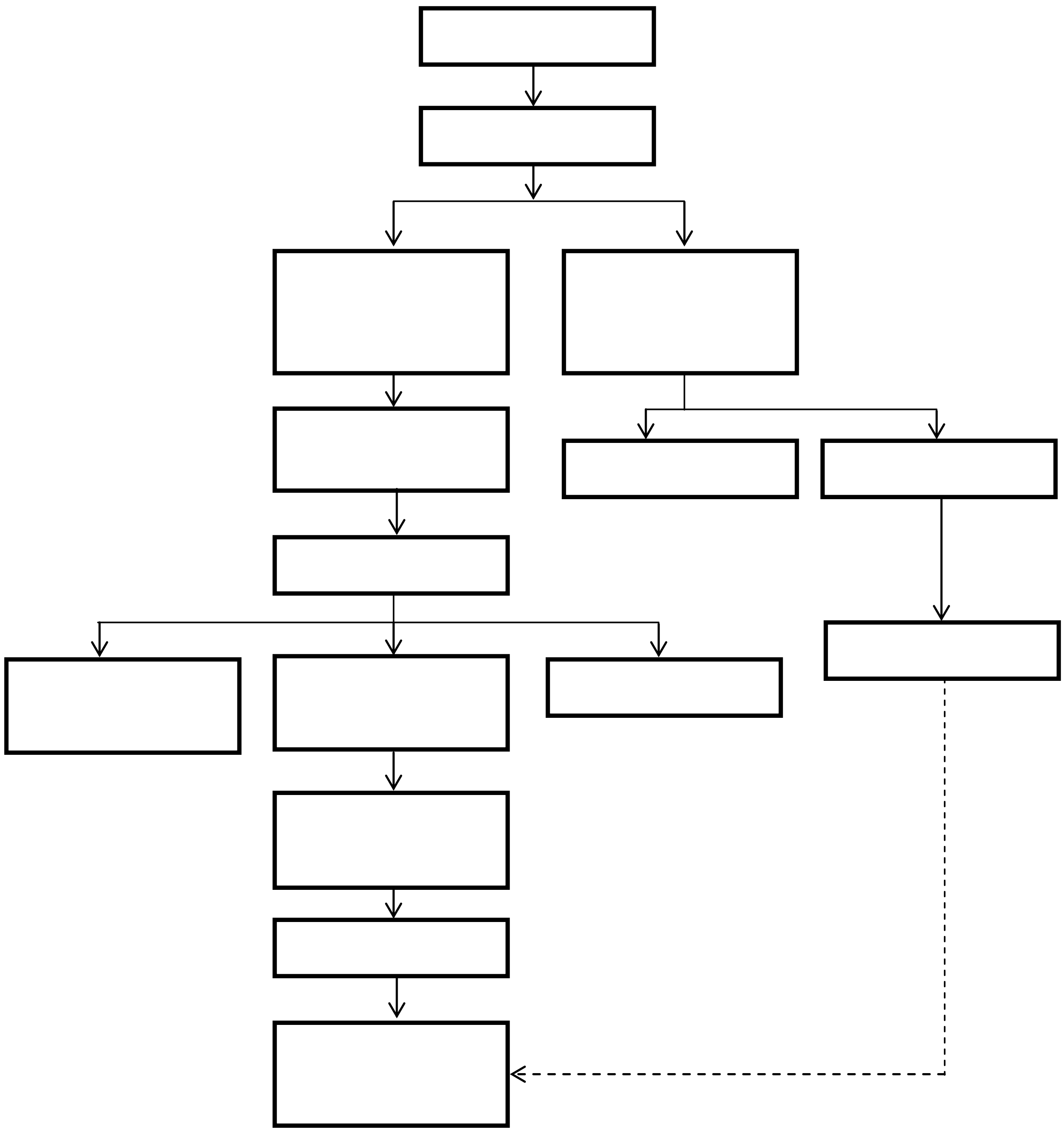


Figure 4.11 Plastic waste management processes (K.S. Rebeiz, 1995)

In Environmental Quality Act 1974, reducing the waste at source or recycling the waste is not part of the legislation yet. If all sectors are required mandatorily to carried out waste minimization policy at their workplace, we can reduced the waste in short period and achieved better environment easily. According to Zaini Sakawi (2010), waste management system in Malaysia is still at early stage from full privatization. It is said some of the factors delaying it are because of lack of fund, no financial resources and the length of the interim period.

Waste minimization barriers mainly because of human attitudes. There are five main barriers identified which are cost, lack of interest, lack of legislation pressure, lack of time and lack of understanding (Paul S. Phillips *et al*, 1998) (Figure 4.12). If we can overcome all the five issues revolving the waste minimization, maybe we can see a different scenario where waste is not an issue at all.

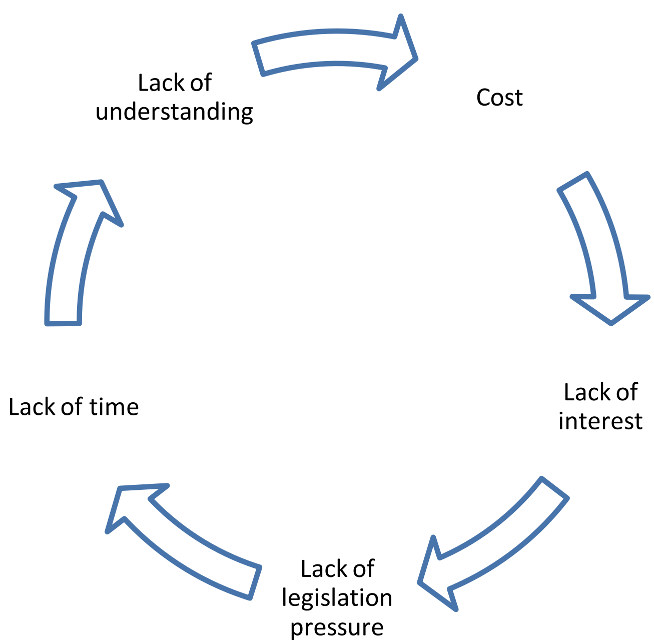


Figure 4.12 Waste minimization barriers related to attitudes

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The rheological properties of bitumen with 80/100 grade penetration changed with the addition of polyethylene as the modifier. Based on softening and penetration test result, polyethylene modified bitumen can resist higher temperature before deformation and improved the resistance to fatigue cracking because of its stiffness.

Polyethylene in pellet form added to the bitumen blend well at low concentration producing homogenous textures as shown in the surface morphology analysis. This is proven by the decrement in penetration and increment in softening point and also viscosity. Though resistance to flow increased as the addition of polyethylene increased do no good for the usage of bitumen binder in the building construction, recent research have been conducted to add catalyst to the modified binder to improve it. Based on viscosity result, the values kept increased as the content of polymer increased. The increment on this property is not good as high viscosity creates complexity in mixing, laying and compaction of the mixture (Burak Sengoz *et al*, 2008)

Polyethylene modified bitumen have higher elastic modulus, G' which give positive impact and reduce possibilities of thermal cracking during application. Thermo gravity also revealed that stability of thermal is achieved for addition of polyethylene from 3% to 10%. Thus, the modified binder is better compared to unmodified binder.

The phase morphology of the polyethylene modified bitumen is influenced by polymer nature and its content (Burak Sengoz *et al*, 2008). As illustrated, there is no morphology variation to bitumen with polyethylene less than 3% only when the concentration of the polymer is more than 5%, a continuous polymer phase with dispersed bitumen phase is observed.

For waste minimization purpose, polyethylene addition to the bitumen binder for building material has been studied. Based on all the evaluations conducted, polyethylene at low concentration enhanced the performance of the bitumen. Further research on the higher content of polymer with additives is believed to benefit all. Hence, an opportunity is wide open for waste minimization can be commercialized in Malaysia and reduces our waste disposal issue.

5.2 Recommendation

Waste management in Malaysia can be improvised with the cooperation from the government, citizen and the enforcement of laws. Most important, understanding on the need to reduce waste at source is the solution to reduce waste at the disposal landfill.

As for now, policy on waste reduction at source is still not implemented. It is believed, drastic positive change will take place on the waste management issue. For instance, reward or incentive also can be given to sectors that support the waste minimization by applying for example cleaner production, treating waste at their workplace and reprocessing waste as by-product.

Further research on all type of waste must goes on in order to transform all of our waste into a material which can benefits us and also the environment in long term. This way, we can improve our way of living and make sure that our environment is still sustainable to live in.

REFERENCES

1. Abdel Aziz Mahrez, Mohamed Rehan Karim. (2010). Rheological Evaluation of Bituminous Binder Modified With Waste Plastic Material. *5th International Symposium on Hydrocarbons & Chemistry (ISHC5)*, Sidi Fredj, Algiers

2. A.I. Al-Hadidy, Tan Yi-qiu, (2008). Effect of polyethylene on life of flexible pavements. *Construction and Building materials*, 23, 1456-1464

3. Anthony L. Andrady. (2003). Plastics and the Environment. Canada. John Wiley & Sons publication.

4. Burak Sengoz, Ali Topal, Giray Isikyakar. (2008). Morphology and image analysis of polymer modified bitumen. *Construction and Building Materials*, 23, 1986–1992

5. Changqing Fang, Ruien Yu, Ying Zhang, Jingbo hu, Min Zhang, Xinghua Mi. (2011). Combined modification of asphalt with polyethylene packaging waste and organophilic montmorillonite. *Polymer Testing*, 31, 276-281

6. Chiemchaisri, C., J. P. Juanga, and C. Visvanathan. (2007). Municipal Solid Waste Management in Thailand and Disposal Emission Inventory. Environ. Monit Assess. *Article in Press*. doi 10.1007/s10661-007-9707-1

7. Cristina Fuentes-Aude´ n, Juan Andre´ s Sandoval, Abel Jerez, Francisco J. Navarro, Francisco J. Martı´nez-Boza, Pedro Partal, Crı´spulo Gallegos. (2008). Evaluation of thermal and mechanical properties of recycled polyethylene modified bitumen. *Polymer Testing*, 27, 1005–1012

8. D. S. Achilias,A. Giannoulis, G.Z. Papageorgiou. (2009). Recycling of polymers from plastic packaging materials using the dissolution-reprecipitation technique. *Polym.Bull*,63,449-465

9. Drozdov Aleksey. D, Yuan Q. (2003). The viscoelastic and viscoplastic behavior of low density polyethylene. *International Journal of Solid and Structure*, vol 40, pp2321-2342

10. Francisco Javier Navarro, Pedro Partal, Francisco J. Martínez-Boza, Críspulo Gallegos. (2010). Novel recycled polyethylene/ground tire rubber/bitumen blends for use in roofing applications: Thermo-mechanical properties. *Polymer Testing*, 29, 588-595

11. Feng Z, Jianying Y, Jun H. (2011). Effects of thermal oxidative ageing on dynamic viscosity, TG/DTG, DTA and FTIR of SBS- and SBS/sulfur-modified asphalts. *Construction and Building Materials*, 25, 129–137.

12. K. S. Rebeiz. (1995). Precast use of polymer concrete using unsaturated polyester resin based on recycled PET waste. *Construction and Building Materials*, Vol. 10, No. 3.

13. K.S. Rebeiz, A.P. Craft. (1995). Plastic waste management in construction: technological and institutional issues. *Resources, Conservation and Recycling*, 15, 245-257

14. M. Garcı´a-Morales, P. Partal, F.J. Navarro, C. Gallegos. (2005). Effect of waste polymer addition on the rheology of modified bitumen. *Fuel*, 85, 936–943

15. Ministry of housing and Local Government (MHLG). (2000). Retrieved September 2012, from Ministry of Housing and Local Government Reports 2000. Kuala Lumpur: http://www.kpkt.gov.my/jspn/main.php%20(8>

16. Ministry of housing and Local Government (MHLG). (2003). *National solid waste management policy*. Retrieved September 2012, from Kementerian Perumahan dan Kerajaan Tempatan: http://www.kpkt.gov.my/jspn/main.php%20(8>

17. M. Naskar, K. S. Reddy, T. K. Chaki, M. K. Divya, A. P. Deshpande. (2012). Effect of ageing on different modified bituminous binders: comparison between RTFOT and radiation ageing. *Materials and Structures*, DOI 10.1617, s11527-012-9966-3

18. M. Naskara, T.K. Chakia, K.S. Reddyb. (2010). Effect of waste plastic as modifier on thermal stability and degradation kinetics of bitumen/waste plastics blend. Thermochimica Acta, Volume 509, 128–134

19. Moise´ s Garcı´a-Morales, Pedro Partal, Francisco J. Navarro, Francisco Martı´nez-Boza, Malcolm R. Mackley, Crı´spulo Gallegos. (2004). The rheology of recycled EVA/LDPE modified bitumen. *Rheol Acta*, 43: 482–490

20. Nasir, M. H., A. R. Rakmi, T. C. Chong, Z. Zulina, and A. Muhamad. (2000). Waste Recycling in Malaysia: Problems and Prospects. *Waste Management and Research*, 18: 320–328

21. Nur Izzi Md. Yusoff a, Montgomery T. Shaw b, Gordon D. Airey. (2011). Modelling the linear viscoelastic rheological properties of bituminous binders. *Construction and Building Materials*, 25, 2171–2189

22. Noor Zainab Habib, Ibrahim Kamaruddin, madzalan Napiah, Isa Mohd Tan. (2010). Rhelogical properties of polyethylene and polypropylene modified bitumen. *World Academy of Science, Engineering and Technology*, 72

23. Oyekunle, L.O. (2007). Influence of chemical composition on the physical characteristic of paving asphalt. *Journal petroleum and technology*, 25(11&12), 1401-1414

24. Paul S. Phillips, Bethan Gronow, Adam D. Read. (1998).A regional perspective on waste minimization: a case study of the East Midlands of England. *Resources, Conservation and Recycling*, 23, 127–161

25. Parviz M. Rahimi, Thomas Gentzis. *National Centre for Upgrading Technology*

26. Practical Action. Recycling Plastics. Retrieved July 10, 2012, from : http://www.solucionespracticas.org.pe/fichastecnicas/pdf/recycling_plastics.pdf

27. Sangita, Tabrez Alam Khan, Sabina, D.K. Sharma. (2011). Effect of waste polymer modifier on the properties of bituminous concrete mixes. *Construction and Building Materials*, 25, 3841–3848

28. Sippy K. Chauhan, Sangita Sharma, Anuradha Shukla, S. Gangopadhyay. (2010). Recent trends of the emission characteristics from the road construction industry. *Environ Sci Pollut Res*, 17, 1493–1501

29. Shell Bitumen. (1995). The Shell Bitumen Industrial Handbook. London: Thomas Telford.

30. Solid Waste Department of Malaysia. (2012). Retrieved Oct 2012, from Solid Waste Department of Malaysia report 2012: http://www.kpkt.gov.my/jpspn/main.php

31. Swapan Kumar Bagui1, Ambarish Ghosh. (2012). Economic And Financial Analysis For Polymer Modified Bitumen. Malaysian Journal of Civil Engineering, 24(1), 96-106

32. The World Bank. (2012b). *Data Malaysia*. Retrieved September 2012, from The world Bank: http://data.worldbank.org/country/malaysia?display=default

33. W. Gutt, P. J. Nixon. (1979). Use of waste materials in the construction industry. Analysis of the RILEM Symposium by Correspondence. *Materiaux et Construction*, Vol 12, No. 70.

34. Xiaohu Lu, Ulf isaacsson. (1999). Modification of road bitumens with thermoplastic polymers. *Polymer Testing*, 20, 77-86

35. Yue Huang,Roger N. Bird, Oliver Heidrich. (2007). A review of the use of recycled solid waste materials in asphalt pavements. Resources, *Conservation and Recycling*, 52, 58-73

36. Zahra Niloofar Kalantar, Mohamed Rehan Karim, Abdelaziz Mahrez. (2012). A review of using waste and virgin polymer in pavement. *Construction and Building Materials*, 33, 55–62

37. Zaini Sakawi. (2010). Municipal solid waste management in Malaysia: solution for sustainable waste management. *Journal of applied science in environmental sanitation*. Volume 6, Number 1, 29-38

38. Zamali Tarmudi, Mohd Lazim Abdullah, Abu Osman Md Tap. (2009). An Overview of Municipal Solid Wastes Generation In Malaysia. *Journal Technology*, 51(F), 1–15

39. (2005). Bitumen safety code, Safety, health and environmental aspects of design,

construction, operation, inspection and maintenance of bitumen manufacture, blending, storage, distribution, product handling and use, and sampling. Model Code of Safe Practice in the Petroleum Industry, Part 11

40. (2002). Plastic: An analysis of plastics consumption and recovery in Western Europe 2000. Association of Plastics Manufacturers In Europe.

APPENDIX A

DATA FOR SOFTENING POINT TEST

Table A1 Softening point result

Polyethylene concentration	**Softening temperature (℃)**		
	Value 1	**Value 2**	**Average**
0%	49	51	50
1%	48	48	48
3%	49	50	50
5%	50	51	51
7%	51	53	52
10%	54	55	55

APPENDIX B

DATA FOR PENETRATION TEST

Table B1 Penetration result

Polyethylene concentration	**Penetration (dmm)**			
	Value 1	**Value 2**	**Value 3**	**Average**
0%	98	100	97	98
1%	120	115	120	118
3%	110	112	114	112
5%	90	89	86	88
7%	55	56	56	56
10%	42	60	57	53

APPENDIX C

DATA FOR BROOKFIELD VISCOSITY TEST

Table C1 Viscosity result

Polyethylene concentration	**Viscosity (mPas)**			
	Value 1	**Value 2**	**Value 3**	**Average**
0%	317	319	323	320
1%	496	375	409	427
3%	463	471	488	474
5%	838	842	842	840
7%	1600	1563	1729	1631
10%	2042	1954	1967	1987

APPENDIX D

DATA FOR DUCTILITY TEST

Table D1 Ductility test result

Polyethylene concentration	**Ductility (dmm)**		
	Value 1	**Value 2**	**Average**
0%	98.0	100.0	99.0
1%	56.5	42.0	32.8
3%	25.0	24.0	16.3
5%	16.5	14.5	10.4
7%	5.5	6.5	4.0
10%	4.0	5.0	3.0

APPENDIX E

DATA FOR THERMOGRAVITY ANALYSIS

Table E1 TGA result for 1% PE binder

Ts [°C]	Value [mg]	Ts [°C]	Value [mg]	Ts [°C]	Value [mg]	Ts [°C]	Value [mg]
33.8656	10.3991	220.933	10.2332	394.38	8.59902	564.26	3.05859
42.016	10.4403	226.467	10.2233	399.223	8.4753	569.651	2.98064
52.2649	10.4023	232	10.2123	404.481	8.42294	574.964	2.90069
61.0526	10.3807	237.528	10.1997	409.919	8.35275	580.146	2.82134
68.8383	10.3665	243.089	10.1863	415.488	8.22157	585.342	2.74316
75.8436	10.3572	248.61	10.1727	421.103	8.03687	590.605	2.66628
82.3604	10.3503	254.175	10.1554	426.829	7.72502	595.9	2.59152
88.5088	10.3448	259.739	10.1371	432.234	7.44209		
94.3934	10.3399	265.3	10.1181	437.71	7.16216		
100.144	10.3363	270.84	10.0969	443.325	6.7984		
105.764	10.3329	276.422	10.073	448.839	6.4058		
111.288	10.3307	281.991	10.0479	454.474	5.96104		
116.779	10.3277	287.539	10.0202	459.865	5.54582		
122.269	10.3246	293.127	9.99116	465.219	5.18121		
127.715	10.3222	298.695	9.96336	470.793	4.79676		
133.16	10.3195	304.291	9.92933	476.306	4.4732		
138.57	10.3163	309.858	9.89265	481.889	4.21302		
144.02	10.3113	315.466	9.85424	487.781	4.01353		
149.491	10.3074	321.094	9.81146	494.737	3.86671		
154.951	10.3022	326.703	9.7669	501.08	3.75762		
160.415	10.2981	332.324	9.71983	506.514	3.67201		
165.861	10.2934	337.915	9.67017	511.257	3.60336		
171.369	10.2891	343.52	9.62052	515.856	3.55537		
176.854	10.2842	349.061	9.56678	520.698	3.51541		
182.319	10.2798	354.589	9.51547	526.003	3.47673		
187.793	10.2742	360.331	9.45127	531.463	3.43304		
193.31	10.2682	366.053	9.36633	536.95	3.38281		
198.829	10.2627	371.697	9.26808	542.421	3.3282		
204.351	10.2555	377.466	9.1375	547.872	3.27136		
209.886	10.2483	383.069	8.99562	553.373	3.20565		
215.391	10.24	388.931	8.8083	558.857	3.1347		

Table E2 TGA result for 3% PE binder

Ts [°C]	Value [mg]	Ts [°C]	Value [mg]	Ts [°C]	Value [mg]
53.8362	10.4	254.071	10.3249	459.675	5.74971
55.8342	10.4761	259.569	10.3049	465.194	5.35163
61.9454	10.4782	264.863	10.2841	470.687	4.96642
67.8044	10.4787	270.738	10.2637	476.173	4.61771
73.5018	10.4798	276.54	10.2376	481.678	4.32552
79.0316	10.4805	282.092	10.2108	487.301	4.10168
84.5639	10.4816	287.607	10.1827	493.213	3.94141
90.004	10.4828	293.138	10.151	500.247	3.82685
95.3998	10.4824	298.667	10.1176	506.512	3.73417
100.816	10.4828	304.238	10.0816	512.047	3.66431
106.181	10.4832	309.724	10.0423	517.112	3.6111
111.56	10.4839	315.373	10.0041	521.679	3.56459
116.961	10.4836	320.908	9.96102	526.343	3.5318
122.34	10.482	326.535	9.91549	531.395	3.498
127.745	10.4807	332.143	9.86588	536.651	3.46131
133.169	10.4787	337.756	9.8146	541.993	3.42206
138.556	10.477	343.361	9.76181	547.432	3.37828
143.985	10.4743	348.84	9.70746	552.883	3.33062
149.443	10.472	354.41	9.65384	558.32	3.27852
154.874	10.4688	360.284	9.58235	563.784	3.22336
160.354	10.466	365.957	9.4944	569.205	3.16707
165.825	10.4622	371.579	9.39147	574.469	3.1047
171.256	10.4585	377.078	9.28206	579.693	3.04218
176.746	10.4549	382.596	9.15809	584.957	2.97989
182.222	10.4505	388.257	8.98967	590.276	2.91565
187.75	10.446	393.689	8.81569	595.583	2.85098
193.24	10.4411	398.778	8.72431		
198.754	10.4347	404.454	8.53737		
204.278	10.4284	409.74	8.39224		
209.795	10.421	415.134	8.27633		
215.323	10.4134	420.61	8.12117		
220.854	10.4044	426.139	7.93416		
226.371	10.3942	432.097	7.5706		
231.916	10.3833	437.723	7.19061		
237.459	10.3698	443.045	6.86284		
243.022	10.3561	448.544	6.51902		
248.479	10.3403	454.122	6.14855		

Table E3 TGA result for 5% PE binder

Ts [°C]	Value [mg]	Ts [°C]	Value [mg]	Ts [°C]	Value [mg]
53.8065	12.5004	248.184	12.4469	448.757	6.20265
55.7781	12.5767	253.716	12.4301	454.13	5.67517
61.8019	12.5764	259.265	12.4121	459.572	5.18731
67.6456	12.576	264.815	12.3929	465.027	4.79936
73.2901	12.5768	270.379	12.3739	470.527	4.52773
78.8718	12.5768	275.942	12.3512	476.36	4.32817
84.3434	12.578	281.473	12.3257	482.608	4.18109
89.7848	12.5786	287.038	12.2982	489.963	4.0769
95.1813	12.5791	292.629	12.2701	496.53	4.00022
100.561	12.579	298.163	12.2397	501.743	3.9455
105.947	12.579	303.757	12.2071	506.451	3.90481
111.297	12.5796	309.35	12.1711	511.027	3.86901
116.698	12.58	314.93	12.1317	515.769	3.83836
122.057	12.58	320.565	12.0879	520.626	3.80788
127.45	12.5795	326.207	12.0377	525.795	3.77903
132.849	12.5788	331.85	11.9813	531.172	3.74914
138.237	12.5772	337.51	11.9165	536.647	3.71704
143.652	12.5775	343.151	11.8444	542.131	3.68043
149.093	12.577	348.756	11.7668	547.642	3.6423
154.526	12.5751	354.357	11.6849	553.129	3.6005
160.015	12.5727	359.928	11.6032	558.629	3.55424
165.477	12.5695	365.492	11.5187	564.093	3.50569
170.957	12.5655	371.09	11.4261	569.434	3.45448
176.437	12.5616	376.905	11.291	574.815	3.40095
181.907	12.5572	382.677	11.108	580.227	3.34627
187.416	12.5539	388.394	10.8843	585.579	3.29132
192.924	12.5484	393.925	10.6367	590.868	3.23719
198.411	12.5422	399.304	10.3942	596.13	3.18221
203.922	12.5357	404.835	10.1128		
209.431	12.5276	410.385	9.79762		
214.94	12.5189	416.108	9.38707		
220.478	12.5103	421.796	8.89429		
226.031	12.5	427.294	8.35128		
231.562	12.4887	432.807	7.79871		
237.099	12.4761	438.232	7.24545		
242.645	12.4626	443.441	6.72943		

Table E4 TGA result for 7% PE binder

Ts [°C]	Value [mg]	Ts [°C]	Value [mg]	Ts [°C]	Value [mg]
53.6338	14.3001	248.118	14.2413	448.417	7.67497
55.655	14.3751	253.656	14.2248	453.765	7.09605
61.7053	14.376	259.221	14.2061	459.078	6.60123
67.5606	14.3764	264.757	14.186	464.451	6.11981
73.2265	14.3761	270.307	14.164	469.895	5.66033
78.7615	14.376	275.877	14.1407	475.371	5.23771
84.2484	14.3755	281.444	14.1159	480.867	4.87362
89.7015	14.3759	286.974	14.0897	486.414	4.58808
95.0807	14.3754	292.538	14.0613	492.251	4.38361
100.496	14.375	298.156	14.0317	498.285	4.24385
105.848	14.3753	303.696	13.998	505.359	4.15462
111.225	14.375	309.294	13.9627	512.174	4.09646
116.605	14.3744	314.871	13.9229	517.811	4.05383
122.006	14.3738	320.486	13.8816	522.857	4.02054
127.367	14.3726	326.122	13.8349	527.776	3.99234
132.761	14.371	331.748	13.7821	532.776	3.96762
138.158	14.3701	337.384	13.7257	537.845	3.94418
143.577	14.3694	342.992	13.6626	542.976	3.92156
149.013	14.3679	348.588	13.5954	548.152	3.8985
154.446	14.3668	354.2	13.5241	553.408	3.87501
159.916	14.3659	359.73	13.451	558.665	3.85108
165.418	14.3629	365.34	13.3714	563.903	3.82784
170.874	14.3589	371.057	13.2642	569.274	3.80238
176.394	14.3558	376.775	13.1222	574.692	3.77526
181.876	14.3522	382.403	12.9526	580.092	3.74785
187.383	14.3475	388.022	12.7354	585.511	3.71778
192.88	14.3422	393.623	12.4666	590.937	3.68644
198.361	14.3366	399.192	12.1566	596.329	3.65497
203.846	14.3285	404.669	11.8272		
209.381	14.3213	410.17	11.4728		
214.891	14.3132	415.687	11.0736		
220.429	14.3044	421.319	10.5641		
225.996	14.2941	426.762	10.0217		
231.496	14.2826	432.055	9.5056		
237.046	14.2691	437.639	8.89915		
242.582	14.2557	443.012	8.30394		

Table E5 TGA result for 10% PE binder

Ts [°C]	Value [mg]	Ts [°C]	Value [mg]	Ts [°C]	Value [mg]
40.867	12.0982	248.473	12.0487	449.198	8.32938
47.596	12.1634	254.036	12.035	454.973	7.77333
56.4467	12.1509	259.567	12.0209	460.592	7.1705
63.9983	12.1443	265.099	12.0044	466.098	6.6053
70.8262	12.141	270.698	11.9866	471.861	5.98257
77.2034	12.139	276.227	11.9666	477.361	5.57717
83.2238	12.139	281.804	11.947	482.766	5.24052
89.0433	12.139	287.392	11.924	488.347	4.99039
94.7198	12.1407	292.938	11.8997	494.175	4.82585
100.285	12.1411	298.522	11.8731	501.319	4.71258
105.827	12.1414	304.071	11.845	507.446	4.62923
111.298	12.143	309.675	11.814	512.302	4.56732
116.726	12.1421	315.254	11.7813	516.877	4.5189
122.157	12.1415	320.84	11.7459	521.544	4.47826
127.583	12.142	326.471	11.7058	526.517	4.44154
133.007	12.141	332.079	11.6635	531.7	4.40257
138.432	12.1404	337.703	11.6167	537.018	4.36226
143.901	12.1395	343.345	11.5668	542.508	4.31748
149.347	12.1384	348.926	11.5112	547.973	4.26987
154.79	12.1364	354.45	11.4559	553.469	4.21842
160.26	12.1351	359.936	11.4084	558.951	4.16139
165.724	12.134	365.531	11.355	564.432	4.09999
171.177	12.132	371.036	11.2985	569.835	4.03403
176.682	12.1309	376.505	11.2484	575.183	3.96567
182.17	12.1284	381.97	11.2042	580.492	3.89603
187.68	12.1251	387.59	11.1324	585.772	3.82723
193.182	12.1211	393.23	11.0473	590.985	3.75778
198.678	12.1173	398.856	10.9325	596.233	3.68806
204.196	12.1137	404.654	10.8046		
209.72	12.1087	410.179	10.6803		
215.23	12.103	416.239	10.3694		
220.773	12.0962	421.625	10.1397		
226.302	12.0892	426.99	9.9276		
231.839	12.0796	432.769	9.54681		
237.396	12.0714	438.246	9.10684		
242.936	12.0604	443.601	8.73223		

APPENDIX F

DATA FOR LANDFILL SITES IN MALAYSIA

Table F1 Landfill quantity according to state

BILANGAN TAPAK PELUPUSAN SISA PEPEJAL YANG BEROPERASI DAN YANG TELAH DITAMATKAN OPERASI MENGIKUT NEGERI SEHINGGA 30 JUN 2012

NEGERI	BILANGAN TAPAK YANG BEROPERASI	BILANGAN TAPAK YANG TELAH DITAMATKAN OPERASI
Johor	14	23
Kedah	8	7
Kelantan	13	6
Melaka	2	5
Negeri Sembilan	7	11
Pahang	16	16
Perak	17	12
Perlis	1	1
Pulau Pinang	2	1
Sabah	19	2
Sarawak	49	14
Selangor	8	14
Terengganu	8	12
Wilayah Persekutuan	1	7
JUMLAH	**165**	**131**
JUMLAH KESELURUHAN	**296**	

Sumber : Jabatan Pengurusan Sisa Pepejal Negara

APPENDIX G

DATA FOR SOLID WASTE GENERATION IN LOCAL AUTHORITIES IN MALAYSIA

Table G1 Solid waste generation in Malaysia

Year	Population (million)	Annual Solid waste generated (Million tonnes)
1991	14	2.5
1995	15	3.0
1996	16	3.2
1997	16	3.4
1998	17	3.5
1999	17	3.7
2000	18	3.9
2005	21	5.9
2010	23	7.0

APPENDIX H

DATA FOR SOLID WASTE COMPOSITION IN MALAYSIA 2005

Table H1 Solid waste composition according to type of waste

Komponen	Peratus
Sisa Makanan	45
Plastik	24
Kertas	7
Metal	6
Kaca	3
Bahan Lain	15
Jumlah	**100**

APPENDIX I

DATA FOR SOLID WASTE DISPOSAL IN MALAYSIA

Table I1 Solid waste disposal according to state

PURATA UNJURAN KUTIPAN SISA PEPEJAL YANG DILUPUSKAN MENGIKUT NEGERI
DARI JANUARI HINGGA JUN 2012

NEGERI	PURATA UNJURAN SISA DILUPUS SETIAP HARI (TAN)
Johor	3,004.95
Kedah	2,078.20
Kelantan	1,622.95
Melaka	807.46
Negeri Sembilan	1,187.90
Pahang	1,501.88
Perak	2,396.30
Perlis	306.80
Pulau Pinang	1,706.59
Sabah	2,136.42
Sarawak	2,027.33
Selangor	4,435.30
Terengganu	1,385.09
Wilayah Persekutuan	3,968.15
JUMLAH	**28,565.32**

Sumber : Jabatan Pengurusan Sisa Pepejal Negara

Nota:
Perangkaan melibatkan sisa domestik dari premis kediaman, komersial dan institusi sahaja
Perangkaan merupakan unjuran daripada Data asal pada Tahun 2002 dengan peningkatan sebanyak 3.59 % setahun

APPENDIX J

DATA FOR RECYCLE PERCENTAGE IN PUTRAJAYA

Table J1 Recycle data according to type of waste in kg

	Feb	Mac	April	May	Jun	Total
Paper	86128	95524	117311	109593	114021	522577
Glass	600	610	489	559	294	2552
Plastic	4512	4286	6366	6504	6736	28403
Metal	4688	4708	6868	6978	7446	30687
Others	384	786	983	1008	2385	5546

APPENDIX K

DATA FOR DYNAMIC SHEAR RHEOMETER

Table K1 Complex shear modulus, elastic modulus and phase angle data

Polyethylene concentration	Dynamic Shear Rheometer		
	Complex shear modulus	**Elastic modulus**	**Phase angle**
1%	186	125	88
3%	297	287	86
5%	813	799	76
7%	972	950	65
10%	1500	1356	48