UTILIZATION OF WASTE HIGH DENSITY POLYETHYLENE (HDPE) AS COARSE AGGREGATE REPLACEMENT AND GLASSES AS FILLER IN HOT MIX ASPHALT

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ABSTRACT

Flexible, rigid and composite are the three typical types of pavements. Commonly, flexible pavement is used especially in municipal, state and federal road in Malaysia. It consists five layers such as subgrade, subbase, base, base course and wearing course. In addition, the main structural function of pavement is to support the vehicles wheel load applied to the road and distribute to the subgrade. High Density Polyethylene (HDPE) which is one of the polymers which is very familiar material used to produce many kind of product such as packing films, pipes and large blow and rotating moulding items while crushed glasses in non-metallic and inorganic material with 2.67 of specific gravity. Flexible pavement is commonly facing three major failures such as rutting, fatigue cracking and thermal cracking. The objective of this research is to investigate the optimum and effect usage of recycled HDPE as coarse aggregate replacement with crushed glasses as filler in modified asphalt mixture by determining the stiffness and permanent deformation. The modified asphalt mixture were produced from content concentrate of waste HDPE fillet range 2%, 4%, 6%, 8% and 10% of the weight of asphalt mixture with sieve size from 3.35mm to 1.18mm and 4% to 6% is the range of the optimum bitumen content of hot mix asphalt wearing course 14 (ACW14) with 80/100 of penetration grade of bitumen by referring Standard Specification for Road Works in Malaysia. The performance of the aggregate and bitumen is complying with Specification of Public Work Department 2008 in Malaysia. Therefore, these aggregates and bitumen can be used as asphalt for modified and unmodified sample. The Repeated Load Axial Test (RLAT), Indirect Tensile Stiffness Modulus Test (ITMS) were used to determine the permanent deformation and stiffness of asphalt, respectively. The density-void analysis indicates that the optimum bitumen content is 5.37% of weight of bitumen content. The result shows that the HDPE modified asphalt with crushed glass could enhance the stiffness of asphalt at 6% aggregate replacement at temperature 30°C. This modification also improves permanent deformation at 1800 cycles. Therefore the HDPE modified asphalt with crushed glasses is suitable to use for road pavement in term of economic and environmental aspects.

ABSTRAK

Lentur, tegar dan komposit adalah tiga jenis turapan jalan. Biasanya, turapan lentur digunakan terutama di kawasan bandar, negeri dan jalan persekutuan di Malaysia. Ia mengandungi lima lapisan seperti subgred, subtapak, asas, lapisan tapak dan lapisan kursus. Selain itu, fungsi utama struktur turapan adalah untuk menyokong beban kenderaan yang dikenakan kepada jalan dan mengagihkan kepada subgred. Berketumpatan tinggi Polyethylene (HDPE) yang merupakan salah satu polimer yang sangat biasa digunakan untuk menghasilkan pelbagai jenis produk seperti pembungkusan filem, paip dan tamparan besar dan berputar item acuan manakala gelas dihancurkan adalah bukan logam dan bahan bukan organik dengan graviti tertentu iaitu 2.67. Turapan lentur biasanya menghadapi tiga kegagalan utama seperti aluran, keretakan kelelehan dan keretakan haba. Objektif kajian ini adalah untuk menyiasat penggunaan yang optimum dan kesan HDPE dikitar semula sebagai pengganti agregat kasar dengan kaca dihancurkan sebagai pengisi dalam campuran asfalt diubahsuai dengan menentukan kekukuhan dan ubah bentuk kekal. Campuran asfalt diubahsuai dihasilkan daripada pekatan kandungan sisa HDPE pelbagai dalam bentuk fillet dalam lingkungan 2%, 4%, 6%, 8% dan 10% daripada berat campuran asfalt dengan saiz ayak dari 3.35mm ke 1.18mm dan 4% hingga 6% adalah lingkungan kandungan optimum bitumen bagi campuran asfalt panas lapisan asphalt konkrit 14 (ACW14) dengan 80/100 gred penetrasi bitumen dengan merujuk Standard Spesifikasi untuk Jalan Raya di Malaysia. Prestasi agregat dan bitumen telah mematuhi spesifikasi Jabatan Kerja Raya 2008 di Malaysia. Oleh itu, agregat dan bitumen boleh digunakan sebagai asfalt untuk sampel diubahsuai dan tidak diubah suai. Ujian Beban Paksi Berulang (RLAT), Ujian Modulus Tegangan Kekukuhan Secara Tidak Langsung (ITMS) telah digunakan untuk menentukan ubah bentuk kekal dan kekukuhan asfalt. Analisis rongga berkepadatan menunjukkan bahawa kandungan optimum bitumen adalah 5.37% daripada berat kandungan bitumen. Hasil kajian menunjukkan bahawa HDPE asfalt diubahsuai dengan kaca dihancurkan boleh meningkatkan kekukuhan asfalt pada 6% penggantian agregat pada suhu 30 ° C. Pengubahsuaian ini juga meningkatkan ubah bentuk kekal di 1800 kitaran. Oleh itu HDPE asfalt diubahsuai dengan kaca dihancurkan sesuai untuk digunakan untuk turapan jalan raya dari segi aspek ekonomi dan alam sekitar.

TABLE OF CONTENTS

CHAPTER 3 METHODOLOGY

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

μm	Micrometre
ρ_w	Density of Water
%	Percentage
ε	Total Strain, Bandwidth Parameter

LIST OF ABBREVIATION

mm	Millimetre
HDPE	High Density Polyethylene
PET	Polyethylene Terephthalate
HMA	Hot Mix Asphalt
ACW	Asphalt Concrete Wearing
ITSM	Indirect Tensile Stiffness Modulus
ITS	Indirect Tensile Strength
RLAT	Repeated Load Axial Test
ACB	Asphalt Concrete Binder
DMA	Dynamic Mechanical Analysis
Pmax	Maximum Applied Load
kPa	Kilopascal
UTM	Universal Testing Machine
LVDTs	Linear Vertical Displacement Transducers
ASTM	American Society for Testing and Materials
C	Celcius
RPM	Revolutions Per Minute
TPF	Ten Percent Fines
kg	Kilogram
cm	Centimetre
BS	British Srandard
Max	Maximum
Min	Minimum
AASHTO	American Association of State Highway and Transportation Officials
OPC	Ordinary Portland Cement
PE	Polyolefins
PP	Poly-Propylene

EVA	Ethylene Vinly Acetate
SBS	Styrene Butadiene Styrene
LDPE	Low Density Polyethylene
TPs	Thermoplastics
$CaCO^3$	Calcium Carbonate
LA	Los Angeles Abrasion
ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
VTM	Voids in Total Mix
VMA	Voids In Mineral Aggregate
VFA	Voids Filled with Biumen
MS	Malaysian Standard
PWD	Public Work Department

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Flexible, rigid and composite are the three typical types of pavements. Commonly, flexible pavement is used especially in municipal, state and federal road in Malaysia. Flexible pavement typically consists of asphalt mixture placed over granular base or subbase layers which supported by the compacted soil referred to as the subgrade (Papagiannakis et al., 2008). Flexible pavement structure consists of subgrade, subbase, base, base course and wearing course. In addition, the main structural function of pavement is to support the vehicles wheel load applied to the road and distribute to the subgrade. The best design of wearing coarse by selection of materials, gradation and bitumen content able to form good skid resistance, desirable stability, durability and good workability which allow the rapid drainage of surface water, minimize traffic noise, resistance cracking, withstand traffic turning and braking force, protect underlying road structure, require nominal maintenance, be capable of being recycled or overlaid and be durable and give the value or money (O'Flaherty,2002).

The sizes and materials of aggregate are different depend on the classification of aggregate which is coarse aggregate and fine aggregate. Coarse aggregate should be retained on 2.4mm sieve opening of crush rock or crushed gravel and free from foreign materials. Meanwhile, fine aggregate should be passing on 2.4mm sieve opening and shall be clean, hard, durable and free from clay, mud and other foreign materials. The typical cross section of a flexible pavement is shown in Figure 1.1.

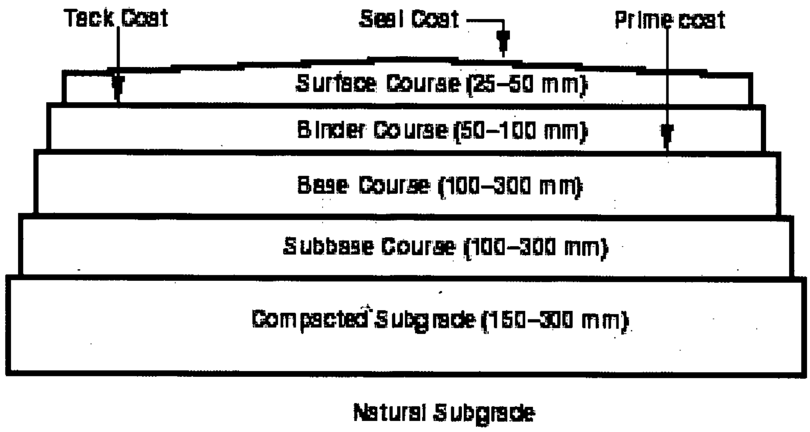

Figure 1.1: Typical cross section of a flexible pavement

Bitumen consists two types of penetration grades, the range is between 60 – 80 and 80 -100. Based on the specification of the JKR/SPJ/2008-S4, the bitumen of penetration grade 60 -80 is recommended to be used for heavy traffic roads in order to achieve higher stability of mixture and to lessen the possibility of bitumen bleeding or flushing at high temperature.

Permanent deformation or rutting is one of the pavement failures due the stress caused by the traffic load pressure. The results from many agencies in world had showed that the failure of permanent deformation is related to the materials in asphalt mixture use for the wearing coarse layer of the pavement (Tayfur et al., 2005). Therefore, reconstruction the sub base or base to increase the strength or overlay rutted area with bituminous surfacing is probable treatment for this condition of flexible pavement.

Rutting from weak subgrade occur in the wheel paths of the vehicle travelling on a flexible pavement as shown in Figure 1.2. The thickness of pavement layers does not provide enough strength to reduce the applied stress to the tolerable level as well as it is weakened by the intrusion of moisture.

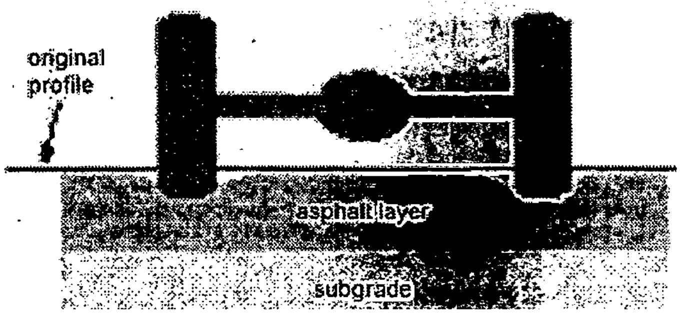

Figure 1.2: Rutting along the wheel path

Nowadays, the pavement layer consists of recycled materials such as plastics and crushed glass. High Density Polyethylene (HDPE) which is one of the types of polymer is a very familiar material used to produce many kind of product such as packing films, pipes and large blow and rotating molding items (Rosato, 2004). The HDPE products are often flexible, corrosion and chemical resistance, lightweight while being extremely tough and at the same time, it can be recycled and reused. In addition, HDPE resins have high strength (Campo, 2008).

Meanwhile the waste glass is non-metallic and inorganic, it can neither be incinerated nor decomposed, so it may difficult to reclaim. It had been used in highway construction as an aggregate substitute in hot mix asphalt paving and most of countries in the world incorporated glass into their road specification which encouraged greater use of the materials. While the use of waste glass as filler in hot mixed asphalt is still not widely experimented (Johy H. Et al.,2011).

Recently, several experiments and testing had been done to improve the properties of asphalt mixture. The properties of waste glass as a filler in hot mix asphalt (HMA) is used to improve the engineering properties of asphalt mixture.

Meanwhile HDPE had proved by modified the bitumen or asphalt mixture using polymers, several properties of asphalt mixture such as temperature susceptibility, fatigue life, and resistance to permanent deformation can be improved (Jain et al., 1992; Panda and Mazumdar, 2002; Tayfur et al., 2005; Yildirim, 2005; Hassani et al., 2005).

1.2 PROBLEM STATEMENT

Malaysia is the developing country where the roads and highways are an important role to connect a place to the other destination or place. Flexible pavement is commonly used in Malaysia and it facing three major failures such as rutting, fatigue cracking and thermal cracking. In this case, I referred at Gambang road because the road condition was very bad and unsatisfactory due to the failures of the road. The failure occurs due to traffic load and the materials use for the construction (Thom, 2008).

In addition, the condition of roads are affecting the safety of road users, therefore the bad condition of road may make the hazard of the road and cause accident frequently during raining day and monsoon season. In the other words, the government and private agencies will spend a lot of money for maintenance works.

Recently, the amount of solid waste such as waste glasses and waste plastics, the waste plastics majority comes from PET and HDPE in Malaysia increase due to human needs. According to the Global Environment Centre, a non-government organization in Malaysia in year 2008, 23 000 tonnes of waste was produced each day in Malaysia, with less 5% of the waste being recycled. However, this amount is expected to rise to 30 000 tonnes by the year 2020 (Global Environment Centre, 2009). The amount of waste generated continues to increase due to the increasing population and development. By applying unsystematic process of extracting a proportion of recyclable items from the main waste, it make all waste simply disposed of in landfills.

1.3 OBJECTIVE

The permanent deformation on asphalt pavement cause rutting, corrugation, depression and shoving on the flexible pavement. Therefore, in the effort to produce durable and long life service asphalt pavement, the study on the modification of asphalt mixture using waste HDPE and crushed glasses as partial replacement aggregate on asphalt concrete wearing 14 (ACW 14). This study is experimental work by using Universal Technical Machine (UTM). The main objectives of the study are:-

1. To determine optimum bitumen content of the asphalt mixture
2. To investigate stiffness modulus by using Indirect Tensile Strength Test (ITMS)
3. To determine permanent deformation behavior of HDPE as replacement coarse aggregate in modified asphalt and crushed glasses as a filler

1.4 SCOPE OF STUDY

This study is mainly based on laboratory experiment. The scope of the research is mainly divided into two part; (i) control mixture and (ii) modified mixture of asphalt for flexible pavement. The both sample, the ACW 14 of aggregate gradation size is used in the design pavement. The modified asphalt is proposed to use in the wearing course. In addition, construction of bituminous layer required a higher cost than the other layers.

Aggregate gradation ACW 14 is mixed with bitumen 80/100 grade of penetration will be used for control asphalt and modified asphalt. The density and air void analysis is made to determine the optimum bitumen content of the control mixture for modified mixture of asphalt. In addition, some portion of coarse aggregate are replaced with the waste HDPE in fillets in range 2% to 10% of modified HDPE with crushed glasses for asphalt mixture modification purpose and to investigate the stiffness of ACW 14 by Indirect Tensile Stiffness Modulus test (ITSM). The Repeated Load Axial Test (RLAT) on the control and modified mixture of asphalt to determine the permanent deformation behavior.

In order to achieve the objective of this research, there are several testing will be conduct which are bitumen and aggregate test, void-density analysis, Indirect Tensile Stiffness Modulus test (ITSM) and Repeated Load Axial test (RLAT). This study will be conducted as follow which is hot mix asphalt wearing course 14 (ACW 14). The gradation limits for asphaltic concrete is shown in Table 1.1 and the design bitumen contents is shown in Table 1.2.

Table 1.1: Gradation Limit of Asphaltic Concrete

B.S Sieve Size (mm)	**ACW 10**	**ACW 14**	**ACB 28**
		% Passing by weight	
37.5	-	-	
28	-	-	100
20	-	100	72 - 90
14	100	90 – 100	58 – 76
10	90 – 100	76 – 86	48 – 64
5	58 – 73	50 – 62	30 – 46
3.35	48 – 64	40 - 54	24 – 40
1.18	22 – 40	18 – 34	14 – 48
0.425	12 – 26	12 – 24	8 – 20
0.15	6 – 14	6 - 14	4 – 10
0.075	4 - 8	4 – 8	3 - 7

Table 1.2: Design Bitumen Contents

ACW 10 (Wearing Coarse)	5.0%– 7.0%
ACW 14 (Wearing Coarse)	4.0% - 6.0%
ACB 28 (Binder Coarse)	3.5%– 5.5%

1.5 SIGNIFICANT OF STUDY

The permanent deformation is the structure damage will cause the accidents to the users. Therefore, a solution for this problem has to be found out. The way to solve this problem is by reduce the probability of the structure failure and increase the service life of roads. Many researchers had proved that the modification of asphalt mixture with the modifier such as polymer can improve the properties of asphalt mixture (Haasani et al., 2005; Zoorob and Suparma, 2000). By improving the properties of permanent deformation performance of asphalt concrete pavement, it will be increase the life service of pavement.

The HDPE product is one of the most popular recyclable plastic solid wastes. Due to mechanical and chemical characteristics of this plastic, it is suitable to be used as modifier in asphalt mixture. This advantage of HDPE is used in this study to design the asphalt mixture that can resist permanent deformation behavior. Besides, from this research, it will help to investigate stiffness characteristics of the modified asphalt compare with the control asphalt and able to determine the optimum effects of the HDPE as an additive in asphalt. By contributing the plastic solid waste into the pavement construction, it can be solve the landfill capacity problem and may reduce the negative impact of the waste materials to the environment with reused it in asphalt pavement.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter is divided by four main parts: flexible pavement, asphalt mixture, polymer and mineral filler (crushed glasses). First part of this chapter is the review on flexible pavement. The flexible pavement consists of major component of flexible pavement structure and types of flexible pavement failure. The levels of flexible pavement structures are wearing course, base, subbase, and subgrade. Besides, the flexible pavement failures are including the permanent deformation, fatigue cracking, stiffness and thermal cracking.

The second part of this chapter is regarding to the asphalt mixture. There are several experiments to evaluate the properties of asphalt mixture such as Indirect Tensile Strength, Static Creep Test and Repeated Load Axial Test. In sub topic aggregate, there are review on aggregate gradation, types of aggregate gradation and aggregate properties.

The polymer part is described about the high density polyethylene (HDPE) and the function of HDPE in modified asphalt. The waste glass or crushed glasses as mineral filler are the last part in this literature review

2.2 FLEXIBLE PAVEMENT

The component of flexible pavement consists of surface course, base, subbase and subgrade. The function of pavement structure is to distribute imposed wheel load over a large area of the natural soil. Flexible pavement which include asphalt concrete, stabilized or granular material, or bound granular material distribute the load over a cone shape area under the wheel, by reducing the imposed unit stresses as depth increases. The shear strength of the soil is usually not high enough to support the traffic load. The shear failures would occur in the wheel path in soils and ruts would form if the vehicles were travel on it. Therefore, the structure of the flexible pavement helps the distribution of load to the lower layer and decreases the failure of the flexible pavement.

Surface course consist of asphalt concrete. The layer is directly contact with the traffic load and provides several characteristics such as friction, smoothness, noise control, rut resistance and drainage. In addition the safety of road users will be assured by the availability of these characteristics and able to prevent the surface water from entering into underlying base, subbase and subgrade. This upper structural layer of material is sometimes is subdivided into two layers: wearing course and intermediate/binder course. The wearing course is the upper layer of the road surface. It must be capable of withstanding the wear and abrasive effects and must possess sufficient stability to prevent it from shoving and rutting under traffic loads. Otherwise, it may improve the skid resistance, minimize the hydroplaning effects at high speeds and improve the wet night visibility. In addition, it serve a useful propose in preventing the entrance of excessive quantities of surface water into the base and subgrade from directly above (John Wiley & Sons, 2004)

Base course located beneath the surface course with the high stability and density. Its principal purpose is to distribute the stresses created by wheel loads acting on sufficiently great to result in excessive deformation or displacement of that foundation layer. The base courses are usually constructed out of aggregate or hot mix asphalt (HMA). Thus layer receive load from upper layer and distribute to the subbase. The rutting and shear failure does not occur in best design of base course (Lavin, 2003).

Subbase is located between the base course and subgrade. The subbase course is composed of either solely granular materials (aggregate), soils or granular material stabilized by an additive. The granular may contains aggregate from sand, deposit from quarry, recycled concrete pavement, slag or other material. The subbase generally consists of lower quality materials than the base course but better than the subgrade soils. Subbase course must have ability to distribute the load and functioning as structural support and also can minimize the intrusion of fines from the subgrade into the pavement structure, improve drainage and minimize frost action damage. In certain case, the subbase course is not always needed or used in flexible pavement structure (Lavin, 2003).

Subgrade is the native material which the pavement structure is placed. It is consisted of natural ground, commonly from cut and fill process. In some cases, subgrade were often been called as the formation level. Two most important characteristic of subgrade are the loads bearing capacity and volume changes. The subgrade must be able to support the loads transmitted from the upper pavement structure. This load bearing capacity is affected by degree of compaction, moisture content and soil type. For soil volume changes due to the exposed to excessive moisture content, while soils with excessive fines may be susceptible to frost heave in freezing areas, (Lavin, 2003)

2.3 FLEXIBLE PAVEMENT FAILURE

Asphalt pavement failure is a complicated phenomenon. It is a result of cumulative damage in different pavement layer (Qudais, 2005). Nowadays, asphalt pavement. Nowadays, asphalt pavement has to sustain increasingly large loads. When these loads are combined with adverse environmental conditions, the distress modes in pavements lead to the rapid deterioration of road structures (Vlachovocova,2005). Flexible pavement is facing the risk of failure in form of rutting (permanent deformation), fatigue cracking and thermal cracking. Indirect Tensile Strength test is to evaluate the asphalt mixture performance.

The permanent deformation or rutting in the asphalt pavement is one of the main reason cause the pavement damage. The permanent deformation in pavement has long been recognized to include two different modes which is compactive deformation (consolidation of layer) and plastic deformation (asphalt shear flow) (Huang, 1996; Gokhale et al., 2005).

Thermal cracking is the cracking in flexible pavement due to cold temperature cycling is commonly referred to as thermal cracks. Thermal cracks typically appear as transverse cracks on the pavement surface roughly perpendicular to the pavement centerline. In addition, these cracks can be caused by shrinkage of the HMA surface due to low temperatures, hardening of the asphalt, and daily temperature cycles. Low temperature cracking is associated with regions of extreme cold whereas thermal fatigue cracking is associated with regions that experience large extremes in daily and seasonal temperatures.

Besides, there are two types of non-load related thermal cracks which are transverse cracking and block cracking. The transverse cracks usually occur first and are followed by the occurrence of block cracking is the type that is predicted by models in this design guide, while the block cracking is handled by material and construction variables (Ara,2004).

Stiffness is the important mechanical characteristic of unbound materials in pavements and the relative stiffness of the various layers dictate the distribution of stresses and strains within the pavement system. Besides, the stiffness of the subgrade and unbound base layer is influence the horizontal tensile strain at the bottom of the asphalt and the compressive vertical strain at the top of the subgrade for a simple three-layer flexible pavement system and those parameters are directly related to the performance of the asphalt fatigue and subgrade rutting. The preferred method use for characterizing the stiffness is the resilient modulus MR which is defined as the unloading modulus in cyclic loading for unbound pavement. In 1986, the AASTHO Design Guides have recommended the resilient modulus for characterizing subgrade support for determining structural layer coefficients for flexible pavements.

Fatigue cracking of flexible pavement is due to horizontal tensile strain at the bottom of the asphaltic concrete. It is commonly referred to as "bottom-up" or "classical" fatigue cracking. The cracks most likely initiate from the top in areas of high localized tensile stresses resulting from tire-pavement interaction and asphalt binder aging (top-down cracking) in thick pavement. Besides, the longitudinal cracks connect forming many sided sharp-angled pieces that develop into a pattern resembling the back of an alligator or crocodile after the repeated loading. The early stage of fatigue cracking on the flexible pavement is shown in Figure 2.1 and types of fatigue in Figure 2.2.

Figure 2.1: Fatigue cracking formation,

Source: Halifax NS, October 29, 2013