INFLUENCE OF RECYCLED HDPE AS PARTIAL COARSE AGGREGATE REPLACEMENT ON PERMANENT DEFORMATION OF MODIFIED ASPHALT MIXTURE

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ABSTRACT

Rutting or permanent deformation is one of the asphalt pavement failures due to stresses caused by the traffic load pressures. This permanent deformation cause rutting failure of structure. This study was done in effort to produce durable and long service life of asphalt pavement by modify the asphalt with waste HDPE. The study on modification of asphalt mixture was proposed to evaluate the effect of using HDPE in pallet form as coarse aggregate replacement on 80/100 grade penetration of bitumen and also to develop optimum quality of modified asphalt mixture content HDPE as aggregate replacement. The HDPE was used to replace coarse aggregate size between 3.35mm until 14mm. Bitumen content used for control specimens was in range between 4%-6%. The aggregate was replaced by HDPE pallets between 10% until 50%. From the individual graph of void, bulk density, and resilient modulus versus bitumen content, the averaged optimum bitumen content (OBC) for control asphalt mix obtained was 4.7%. This OBC value was used to produce modified specimen with waste HDPE. Three modified samples were produce for each percent of HDPE replacement. A 20% coarse aggregate replacement by volume results in reduction in bulk density of 13.6%. Modified asphalt was affected by temperature which is the reduction of resilient modulus value at 20°C and 40°C was 82.5%. HDPE was found can increase the ability of asphalt mix to resist permanent if the appropriate percent of HDPE content use. In conclusion, at optimum bitumen content 4.7% and optimum HDPE content 20%, the modified asphalt mixture produce the optimum performance in form of permanent deformation behavior with the lowest strain value.

ABSTRAK

Alur atau deformasi kekal adalah salah satu kegagalan jalan berturap aspal kerana tegangan yang disebabkan oleh tekanan beban lalu lintas jalan. Deformasi kekal ini menyebabkab kegagalan alur terhadap struktur jalan. Penelitian ini dilakukan dalam usaha untuk menghasilkan jalan yang tahan lama dan meningkatkan hayat perkhidamatan aspal dengan mengubahsuai aspal dengan sisa HDPE . Kajian tentang pengubahsuaian campuran aspal dicadangkan untuk menilai pengaruh HDPE dalam bentuk pallet sebagai pengganti agregat kasar pada penetrasi 80/100 grade aspal dan juga untuk menghasilkan kualiti optimum campuran aspal dan HDPE. HDPE ini digunakan untuk menukar saiz agregat kasar antara 3.35mm hingga 14mm. Peratus kandungan bitumen digunakan untuk spesimen kawalan berkisar antara 4%-6%. Agregat digantikan oleh palet HDPE adalah antara 10% hingga 50%. Dari graf individu void, bulk density, resilient modulus melawan aspal, kadar purata aspal optimum (KAO) untuk campuran aspal kawalan diperolehi 4.7%. KAO ini digunakan untuk menghasilkan spesimen yang diubahsuai dengan sisa HDPE. Tiga sampel yang diubah dihasilkan untuk setiap peratus penggantian HDPE. Penggantian 20% agregat kasar menghasilkan pengurangan ketumpatan bulk sebanyak 13.6%. Aspal yang diubahsuai dipengaruhi oleh suhu yang menyebabkan perbezaan penurunan nilai resilient modulus pada suhu 20°C dan 40°C sehingga 82.5%. HDPE didapati boleh meningkatkan kemampuan campuran aspal untuk menahan deformasi kekal jika peratus HDPE menggantikan agregat kasar digunakna dalam kuantiti yang betul. Sebagai kesimpulan, pada kadar aspal optimum 4.7% dan kadar peratus HDPE 20%, campuran aspal yang diubahsuai menghasilkan prestasi yang optimum dalam bentuk perilaku deformasi kekal.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Flexible, rigid and composite are the three typical types of pavements. Most roads especially municipal, state and federal road in our Malaysia are built from flexible type. Flexible pavement typically consists of asphalt mixture placed over granular base/subbase layers 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 coarse. The main structural function of pavement is to support the vehicle wheel load applied to the road and distribute it to the subgrade. The wearing course is the upper layer which is directly contact with traffic load and normally contain of highest quality of materials compared to other materials in other layers. The best design of wearing course is it should offer good skid resistance, allow for the rapid drainage of surface water, minimize traffic noise, resist cracking and rutting, withstand traffic turning and braking forces, protect underlying road structure, require nominal maintenance, be capable of being recycled or overlaid and be durable and give the value for money (O'Flaherty, 2002).

Rutting or permanent deformation is one of the pavement failures due to stresses caused by the traffic load pressures. As reported in many agencies in the world, the permanent deformation failure is related to the materials in the asphalt mixture use for the wearing course layer of the pavement (Tayfur et al., 2005).

Nowadays, the High Density Polyethylene (HDPE) which is one of the type of polymer is a very familiar material used to produce many kind of products such as packaging films, pipes and large blow and rotating molding items (Rosato, 2004). The HDPE products are often flexible, corrosion and chemical resistant, lightweight while being extremely tough and at the same time they can be recycled and can be reused. In addition, HDPE resins have high strength (Campo, 2008).

In year 2007, Huang and his colleagues have reviewed of the use of recycled solid waste materials in asphalt pavement. For their study they selected waste glass, steel slag, tyres materials. They reviewed standards and literature for technical requirements, as well as the performance of asphalt pavements constructed using such recycled materials. They have found that each recycled solid waste materials have more than one potential. Diverting solid waste material such as polymers products into pavement use save landfill area and reduce the demand for quarrying minerals. These recycled plastics can either replace a portion of aggregates, or serve as a binder modifier (Huang et al., 2007).

Recently, several experiments and testing have been done to improve the properties of asphalt mixture. It includes modification on bitumen and/or asphalt mixture. From the laboratory and field study have done before, it proved that by modified the bitumen and/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

As a developing country, Malaysia roads and highways play an important role to connect a place to another place. Mostly, roads in Malaysia are flexible pavement type. The flexible pavements are facing three major failures such as rutting, fatigue cracking and thermal cracking. This failure occurs due to the traffic load and the materials use for the construction (Thom, 2008). The conditions of the roads are affecting the safety of road users. If the road is in bad condition, it can become a hazard and cause road accident. Unfortunately, the road problem occurs frequently especially after raining of monsoon. The road structure can not resist change of weather and load from the traffic bring the damage or failure of the structure. On the other hand, this failure of the road pavement causes the government or the private agencies to spend a lot of money for maintenance work.

Recently, the amount of solid waste including waste plastics majority come from PET and HDPE in Malaysia increase due to development and human need. This waste is one of major environmental problems in Malaysia. According to Global Environmental Centre, a non-government organization in Malaysia, in year 2008, 23 000 tonnes of waste was produced each day in Malaysia, with less than 5% of the waste was 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 Objectives

The permanent deformation on asphalt pavement causes rutting failure of structure. In the effort to produce durable and long service asphalt pavement, the study on the modification of asphalt mixture using waste HDPE is proposed to find it permanent deformation behavior. The main objectives of the study are:

1. To evaluate the effect using HDPE in pallet as partial coarse aggregate replacement on 80/100 grades of penetration of bitumen.
2. To develop optimum quality of modified asphalt mixture content HDPE as partial coarse aggregate replacement in form of permanent deformation behavior

1.4 Scope of Work

This study is mainly based on laboratory experiment. The scope of this research is mainly divided into two part; (i) design conventional and (ii) design modified asphalt mixture for flexible pavement. The sample is proposed for using as wearing course layer in flexible pavement. This AC14 aggregate gradation size is used in both conventional and modified asphalt mixture. Aggregate gradation AC14 is used for wearing course layer. Construction of bituminous layer requires a higher cost than the other layers.

Aggregate gradation AC14 was mixed with bitumen 80/100 grade of penetration for both modified and unmodified mixture. Density and void analysis was done to find the optimum bitumen content of the unmodified sample and used the value for the modified mixture. Some portion of the coarse aggregate were replaced (by volume) with the waste HDPE in pellets form in five different percentage which is 10%, 20%, 30%, 40% and 50% for asphalt mixture modification purpose. The Repeated Load Axial Test was done on the conventional and modified mixture to evaluate its permanent deformation behaviour. The Repeated Load Axial Test is the easiest way to get rutting value and available at laboratory due to the time frame.

1.5 Significant of Study

The permanent deformation of road make the structure damage and harm the road users therefore, a solution for this problem has to be found out. One way to solve this problem is by reduce the probability of the structure to fail and increase the service life of roads. It already proved by the previous researcher that modification of asphalt mixture with 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 service life of pavement. The road which is can be used for long time duration consequently gives the government or private company benefit because they can save the cost for road maintenance or reconstruction.

The HDPE product is one of most popular recyclable plastic solid waste. Due to mechanicals 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 behaviour. By contributing the plastic solid waste into the pavement construction, it can be a solution for landfill capacity problem. Even the amount of solid waste will be recycle is not in huge capacity but this recycle activity significant in reduce the quantity of solid waste material.

CHAPTER 2

LITERATURE REVIEW

This chapter is divided by three main parts: flexible pavement, asphalt mixture, and polymer. First part of this chapter is the review on flexible pavement. In this flexible pavement part, it consists of major component of flexible pavement structure and types of flexible pavement failure. The flexible pavement structures are wearing course, base, subbbase, and subgrade. Meanwhile, the flexible pavement failures are including permanent deformation, fatigue cracking and thermal cracking.

The second part of this chapter is regarding to the asphalt mixture. There are several tests to evaluate the properties of asphalt mixture such as Indirect Tensile Strength, Static Creep Test, Repeated Load Axial Test and Hamburg Wheel Tracking Test. After asphalt mixture tests explanation is followed by the basic components in asphalt mixture; bitumen and aggregates. In sub-topic aggregate there are review on aggregate gradations, types of aggregate gradation and aggregate properties.

Last part of this literature review is on polymer. The polymer part describe about polyethylene and HDPE. Lastly, there is a review about HDPE functions as bitumen modifier.

2.1 Flexible pavement

The components of flexible pavement consist 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 bound granular material, or granular material only, distribute the load over a cone-shaped area under the wheel, reducing the imposed unit stresses as depth increases. The shear strength of the soil is usually not high enough to support the traffic load. If the vehicles were to travel on the natural soils itself, shear failures would occur in the wheel path in most soils and ruts would form. The structure of flexible pavement helps the distribution of load to the lower layer and decreases the risk of pavement failure and as shown in Figure 2.1 (Atkin, 2003).

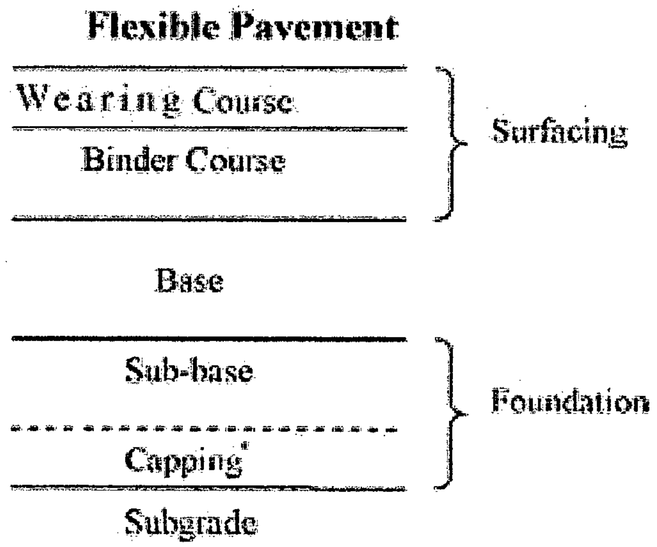

Figure 2.1: Typical structural layers of flexible pavements (Huang, 2007).

Surface course consist of asphalt concrete. This layer is directly contact with traffic loads. It provides characteristics such as friction, smoothness, noise control, rut resistance and drainage. These characteristics of surface course give comfortable and save roadway for the drivers. In addition, it prevents entrance of surface water into the underlying base, subbase and subgrade. This top structural layer of material is sometimes subdivided into two layers: the wearing course and intermediate/binder course. The wearing course is the top layer of road surface. It must be tough to resist distortion and provide smooth and skid resistance riding surface because it directly contact with traffic loads while binder course layer is under wearing course which is it purpose is to distribute load (NAPA, 2001).

Base course is located beneath the surface course. It provides additional load distribution and contributes to drainage and frost resistance. The base courses are usually constructed out of aggregate or hot-mix asphalt. Thus layer receive load from upper layer and distribute to the subbase. To form a good structure, the base course must not fail in terms of shear failure and rutting (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 others 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 load. The base course functions as structural support and also can minimise the intrusion of fines from the subgrade into the pavement structure, improve drainage and minimise frost action damage. In certain condition, the subbase course is not always needed or used (Lavin 2003).

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

2.2 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 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. Several experimental tests can be done to evaluate the asphalt mixture performance such as static creep test, dynamic creep test, indirect tensile strength test, indirect tension test, wheel tracking test and others.

The permanent deformation 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). This kind of failure is one of control factors in many countries' pavement design guide (Gao, 2009).

Fatigue is one of the main distress modes of asphalt pavements. Fatigue characteristics of asphalt mixture is usually determined by continuous loading test, and the corresponding fatigue evaluation indexes are also proposes in continuous loading test, such as DER (Dissipated Energy Ratio), DR (Damage Rate), 50% reduction in initial complex modulus and so on. Now there are some researches about the fatigue characteristic of asphalt mixture in loading with interval, such as Goodrich in year 1998 and 1999; Christensen and Anderson in year 1992; Smith and Hesp in year 2000; and Kim et al. in year 2003. They used dynamic mechanical analysis (DMA) to characterize fatigue characteristic of asphalt mixture in loading with rest interval. All the researchers showed that the fatigue life was longer in loading with rest interval than the fatigue life in continuous loading, and asphalt can heal during rest periods (Tan, 2008).

Thermal cracking is mitigated by the selection of bitumen as asphalt binder with the proper low temperature properties. Temperature variations within the pavement structure contribute in many different ways to the distress and possible failure of that structure. The structural performance of pavements is highly dependent on the temperatures to which these pavements are exposed. Daily and seasonal variations of maximum, minimum, average, and gradient across the pavement depth must be considered in determining thermal stresses and design parameters of flexible pavements (Abdul Wahhab et al., 1994; Bissada, 1972).

In the flexible pavement, on the other hand, the extreme temperatures, maximum and minimum, can cause different problems in the pavement structure. Moreover, the flexible pavement has low thermal conductivity and heat capacity and so is subject to greater variation of temperature. In flexible pavements, asphalt mixture is a visco-elastic material that is closer to being elastic at low temperatures and viscous at high temperatures (Ramadhan and Al-Abdul Wahhab, 1996).

At low temperatures, as the pavement has a tendency to contract, tensile stresses develop and friction between the pavement and the base layer resists this contraction. If the build-up of internal stresses exceeds the strength of asphalt concrete mixtures, micro cracks develop on the surface and the edge and penetrate to full depth under the action of repeated temperature cycles (Jung and Vinson, 1993).

2.3 Asphalt Mixture Properties Evaluation

In order to withstand tire and weather, pavement wearing course layers contain the strongest and most expensive materials in road structure. Characteristics they exhibit like friction, strength, noise and ability to drain off surface water are essential to vehicle's safety and riding quality. Some are already associated with a standard test method. Apart from the nature of component binder and aggregates, asphalt performance strongly depends on the asphalt mixture type. Selection of a type for wearing course layers has to consider a multitude of factors including traffic, climate, condition of existing surface, and economics. No single asphalt mixture type could provide all the desired properties, often some are improved at the expense of others, making the selection difficult and contentious (Huang et al., 2007). The experimental testing for asphalt mixture properties evaluation consists of Indirect Tensile Strength test, Static Creep Test, Repeated Load Axial Test, and Hamburg Wheel Tracking Test.

2.3.1 Indirect Tensile Strength Test

In the indirect tensile strength test (ITS), cylinder specimen are subjected to compressive loads, which act parallel to and along the vertical diametral plane using the Marshall loading equipment. This creates uniform tensile stresses perpendicular to the reaction of applied load and along the vertical diametral plane, which ultimately causes the specimen to fail splitting along the vertical diameter. Based upon the maximum load carried by a specimen at failure, the ITS is calculated from the following equation:

Indirect tensile strength (ITS) = $(2P_{max})/\pi td$

where P_{max} is maximum applied load, t the average height of specimen, and d is the diameter of specimen (Zoorob, 2000).

2.3.2 Static Creep Test

This test is considered to be very important in obtaining data for estimating potential deformation of vehicles wheel path and ranking bituminous mixtures on the basis of their resistance to permanent deformation. The static creep test is conducted by using Universal Testing Machine (UTM). The tests are performed by capping the two sided of the specimen, and then it is placed in the loading machine under a conditioning stress of 10 kPa for 10 min. After that, the conditioning stress is moved and a stress of 100 kPa is applied for 1 h. After the load is removed, the deformation recovery is monitored for 15 min. The initial height of specimen is measured before capping while the axial deformation is monitored during the creep test using the linear vertical displacement transducers (LVDTs).

A cumulated microstrain is calculated as the ratio between the measured deformations to the initial specimen height according to the following equation:

$$\varepsilon = \Delta h/h_0$$

where ε is the accumulated microstrain occurred in the specimen during a certain loading time at a certain temperature, h_0 is the initial specimen height (the initial distance between specimen loading surfaces)(mm), and Δh is the axial deformation (reduction in distance between specimen loading surfaces)(mm x 10^{-6}) (Abo-Qudais, 2007).

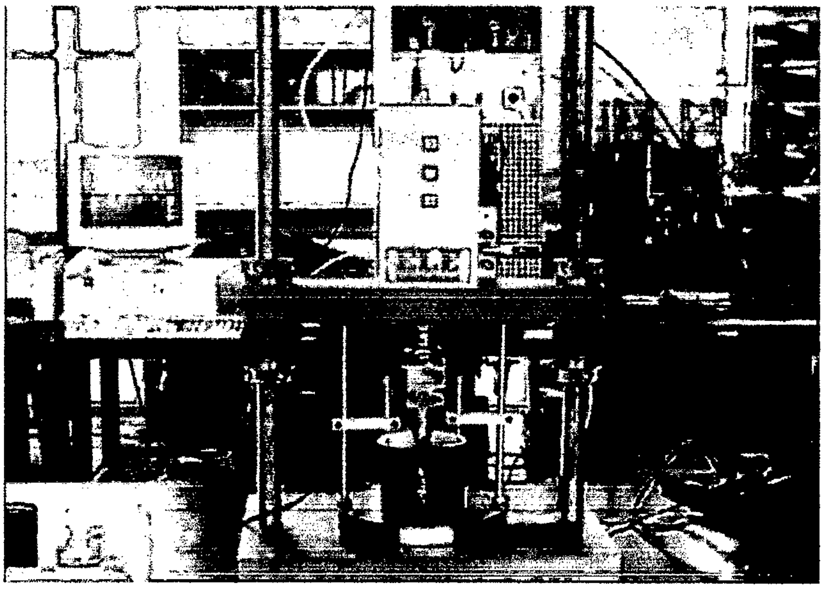

Figure 2.2: Typical static creep test setup (Abo-Qudais, 2007)