ENGINEERING PROPERTIES OF WARM MIX ASPHALT INCORPORATING FLY ASH

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SCHOOL OF CIVIL ENGINEERING
UNIVERSITI SAINS MALAYSIA
2017

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This dissertation is submitted to

UNIVERSITI SAINS MALAYSIA

As partial fulfilment of requirement for the degree of

BACHELOR OF ENGINEERING (HONS.)
(CIVIL ENGINEERING)

School of Civil Engineering,
Universiti Sains Malaysia

June 2017

SCHOOL OF CIVIL ENGINEERING
ACADEMIC SESSION 2014/2015

FINAL YEAR PROJECT EAA492/6
DISSERTATION ENDORSEMENT FORM

Title: **ENGINEERING PROPERTIES OF WARM MIX ASPHALT INCORPORATING FLY ASH**

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I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

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ACKNOWLEDGEMENT

First and foremost, I would like to express my greatest gratitude to my supervisor, Dr Mohd Rosli Bin Mohd Hasan for his endless guidance, motivation, and supports. Thank you for your patience to guide and lead me throughout the project. Thank you for the sharing of your experience and encouragement during my hard time.

Secondly, I would like to take this opportunity to express my appreciation to the technicians of Highway Laboratory, Universiti Sains Malaysia, Mr Mohd Fauzi bin Ali and Mr Zulhairi Arifin for their excellent support, co-operation and guidance throughout my laboratory works. I am also grateful to postgraduate student, Teh Sek Yee, my fellow friends, Kam Pui Kuan and Pavanithan A/L Nathan for their opinions and supports.

Last but not least, I would like to give special thanks to my parents, Lee Kiang Teng and Wong Min Hui, who always support me with their love and guidance. They gave me strength and confidence to complete the project.

ABSTRAK

Sisa pelupusan berlebihan disebabkan oleh pertumbuhan pesat industri pembinaan merupakan satu isu yang perlu diatasi. Dengan memperkenalkan abu terbang kepada industri pembinaan, ia dapat mengurangkan masalah pencemaran. Prestasi asfalt campuran mengguna abu terbang sebagai pengisi mineral telah dinilai. Ciri-ciri perkhidmatan sampel kawalan dan asfalt campuran mengguna abu terbang telah dinilai dengan menggunakan indeks kebolehkerjaan dan indeks tenaga pemadatan bagi menunjukkan upaya proses pembuatan, pengendalian dan pemadatan asfalt campuran. Dari keputusan ujian, abu terbang menunjukkan kebolehkerjaan dan tenaga pemadatan yang lebih baik berbanding dengan sampel kawalan. Analisi ciri-ciri perkhidmatan dan prestasi asfalt campuran mengandungi Sasobit (2% dan 4%) dan suhu pencampuran yang berbeza (130˚C dan 145˚C) juga amat penting. Bagi mensimulasi keadaan sebenar di tapak selepas pemampatan turapan, asfalt campuran yang mempunyai 4% lompang udara telah digunakan untuk menilai ciri-ciri kejuruteraan melalui kekuatan tegangan tidak langsung dan ujian modulus berdaya tahan. Asfalt campuran dengan kandungan Sasobit dan suhu campuran yang lebih tinggi didapati mumpunyai kekuatan tegangan tidak langsung dan modulus berdaya tahan yang lebih baik. Sementara itu, kerosakan lembapan diaplikasikan pada asfalt campuran yang mempunyai 7% lompang udara dengan menggunakan dipercepatkan makmal saturator vakum untuk menunjukkan keadaan sebenar di tapak. Daripada keputusan yang diuji, prestasi asfalt campuran menunjukkan tiada konsisten dalam kerosakan lembapan. Oleh itu, lanjutan kajian hendaklah dijalankan bagi menambahbaik prestasi asfalt campuran.

ABSTRACT

Excessive waste disposal due to the rapid growth in the construction industry is an issue to be solved. Fly ash was introduced in the construction industry to reduce the pollution problems. The performance of warm mix asphalt incorporated fly ash as the mineral filler was evaluated. The service characteristics of the control sample and warm mix asphalt incorporated fly ash was determined using workability index and compaction energy index to indicate the ease which allows producing, handling, placing and compacting of asphalt mixtures. From the results obtained, fly ash shows better workability and compaction energy as compared to the control sample. Analysis of service characteristics and mixture performance of warm mix asphalt incorporated Sasobit (2 % and 4%) and mixed at a different mixing temperature (130˚C and 145˚C) was also important. In order to simulate the actual condition on site after paving, asphalt mixtures with 4% air voids were used to evaluate the engineering properties of asphalt mixtures in term of indirect tensile strength and resilient modulus. The asphalt mixture with higher Sasobit content and mixed at higher temperature found to have a better indirect tensile strength and resilient modulus. Meanwhile, moisture damage was applied to asphalt mixture with 7% air voids using accelerated laboratory vacuum saturator to indicate the actual condition on site. The mixture performance was studied using tensile strength ratio. From the tested results, the performance of the warm mix asphalt shows the inconsistency to moisture susceptibility. Therefore, further studies should be carried out to improve the warm mix asphalt.

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
AC	Asphaltic Concrete
AI	Aging Index
ALVS	Accelerated Laboratory Vacuum Saturator
ASTM	American Society for Testing and Materials
BSG	Bulk Specific Gravity
CDI	Compaction Densification Index
CEI	Compaction Energy Index
FA	Fly Ash
FT	Fischer-Tropsch
HL	Hydrated Lime
HMA	Hot Mix Asphalt
ITS	Indirect Tensile Strength
OPC	Ordinary Portland Cement
PWD	Public Work Department
TSR	Tensile Strength Ratio
UTM	Universal Testing Machine
WI	Workability Index
WMA	Warm Mix Asphalt

CHAPTER 1

INTRODUCTION

1.1 Background

Waste management is the critical problems due to an extensive amount of waste material produced daily. Environmental concerns and diminishing landfill space created an urgent to look for better ways to recycle waste materials. Fly ash, a by-product of coal-fired power generation is used in the protection of asphalt mixtures. Although fly ash is commonly used as a mineral admixture in Ordinary Portland Cement for rigid pavement, it has a very limited use in a flexible pavement. Yet, the use of fly ash as mineral filler is not a new concept. There were studies on the effectiveness of fly ash as replacements for Ordinary Portland cement and hydrated lime in the production of asphalt mixtures. This is thus promoting the fly ash to be an added value product instead of waste product.

In Malaysia, hot mix asphalt (HMA) is the most common applications for road pavements. Nevertheless, warm mix asphalt (WMA) has also been introduced to the industry. WMA has a typical lower production temperature of 20˚C to 40˚C compare to HMA which is around 160˚C (Bayazit et al., 2014). WMA are produced to achieve the goal which is to obtain a level of strength and durability equivalent to or better than HMA.

There are three WMA technologies such as foaming, organic additives and chemical additives. In this research, Sasobit was used as additive for the preparation of WMA samples. Sasobit has ability to lower the viscosity of asphalt binders. This decrease in viscosity allows the working temperatures to be decreased by 18˚C to 54˚C (West et al., 2014).

The primary concerns of the WMA are potential for rutting and moisture damage. In WMA, a lower mixing and compaction temperatures allowed the binder to experiences less aging and less stiff thus potentially prone to rutting. Moisture susceptibility is a concern with WMA because the aggregates are not exposed to the higher mixing temperatures associated with HMA and, therefore, may not be dried completely.

The focus of this study is on the use of fly ash in replacing the filler that typically used in Malaysia such as Ordinary Portland Cement and hydrated lime as specified in the Malaysia Public Work Department (PWD) specifications for roadwork. The analysis is carried out to investigate the fly ash on promoting the performance and engineering properties of WMA in terms of resistance to moisture damage, permanent deformation and cracking. In the end of the study, the environmental advantages should also be identified for WMA and for the use of the waste materials.

1.2 Problem Statement

The typical fillers for asphalt mixture are Ordinary Portland cement and hydrated lime that specified in the Malaysia PWD specifications for roadwork. Fly ash, as a by-product is suggested to replace the ordinary filler for asphalt mixture. It is therefore necessary to evaluate the performance of asphalt mixtures blended with fly ash. Experimental works were carried out to investigate the fly ash on boosting the performance and engineering properties of WMA in terms of resistance to moisture damage, permanent deformation and cracking. Fly ash also adopted to further lower the life cycle emission and energy consumption of WMA as compared to HMA.

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1.3 Objectives

The specific objectives of this study are as follows:

1. To evaluate the possibilities of using fly ash as a mineral filler in improving the engineering properties of WMA.
2. To determine the service characteristic of WMA incorporating fly ash as mineral filler and compare with the control sample.
3. To analyze the mixture performance of WMA incorporating Sasobit and various mixing temperature.

1.4 Significance of Study

Disposal and management of fly ash is a major problem in coal fired thermal power plants. The application of fly ash in asphalt mixture has great potential to lower its impact on the environment. In this study, fly ash was used as an alternative mineral filler to replace ordinary Portland cement and hydrated lime for the production of asphalt mixture. The results from this study can act as a guide to select the types of mineral filler to construct a most economical road pavement with a good strength.

Apart of this, WMA technology was used in this research. The performance of WMA is depending on the amount of WMA additive and production temperature. Therefore, it is necessary to investigate the engineering properties of WMA subjected to different contents of WMA additive at different production temperatures. The mixture performance tests can provide good references to characterize the effect of different additive content at each production temperature. The outcomes of the research can provide useful information on WMA performance while incorporating fly ash compare with control sample.

1.5 Scope of Works

The asphalt mixtures are prepared for HMA and WMA by incorporating Ordinary Portland Cement and Fly Ash as the mineral filler. Asphalt binder grade 80/100 is adopted for this study. Sasobit as the additive for WMA was applied at 2% and 4% based on the weight of asphalt binder at different mixing and compaction temperatures. Mixing temperature used for the HMA is at 160˚C, and 150 ˚C for the compaction process. Meanwhile, the WMA samples were prepared at the different temperature, mixed at 130˚C and 145˚C, and then were compacted at 120˚C and 135˚C, respectively.

The specimens were produced at two air voids, which were 4% air void and 7% air void. All the specimens were subject to short-term aging. The specimens for the resilient modulus and indirect tensile strength (ITS) tests were prepared at 4% air voids. Assessment on the resistance to moisture damage was conducted on the samples with 7% air voids. The Accelerated Laboratory Vacuum Saturator (ALVS) was used for the sample conditioning process to mimic the severe moisture damage condition in the tropics. The moisture damage test result was presented in term of tensile strength ratio (TSR) by comparing the ITS value for wet and dry specimens.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Disposal management always the major issues irritating everyone either due to the environmental concerns or lack of the landfill spaces. Therefore, it is an urgent to look for a better way to recycle or reuse the waste materials to reduce the waste products. The waste materials that are commonly known are blast furnace slag, fly ash, silica fume, recycled aggregates, solid waste, plastic waste and rubber waste (Kolisetty and Chore, 2013). Partial replacement of any of the waste product will be a great help in reducing environmental pollution. Fly ash, a by-product of coal-fired power plants was found to be environmentally hazardous. However, it is known to possess some cementing characteristics (Asi and Assa'ad, 2005). This is thus made the fly ash an added value product to the industry instead of waste to be disposed of. Although fly ash is commonly used as a material in replacing cement, it has a very limited use in flexible pavement (Kolisetty and Chore, 2013). However, the use of fly ash as mineral filler is not a new concept. There were studies on effectiveness of fly ash as replacements for ordinary Portland cement and hydrated lime in production of asphalt mixtures.

In Malaysia, hot mix asphalt (HMA) is used as the primary material for road pavement. The primary sources of emissions found in an asphalt plant are the mixers, dryers, and hot bins. The product of emissions such as dust, smoke, and other gaseous pollutants cause the negative impact to the environment. In order to reduce the emissions from the asphalt plant, WMA technology is introduced as a means to reduce the mixing and compaction temperatures of asphalt mixtures (Gandhi, 2008).

2.2 Introduction to Warm Mix Asphalt

In Malaysia, hot mix asphalt (HMA) is widely used in road construction industries for the road pavement. The warm mix asphalt (WMA) technology, which was developed in Europe, becomes an attention of construction industry (Li et at., 2015). Typically, production temperature of HMA is at 160˚C which is higher than WMA. WMA can be produced at 20˚C to 40˚C lower temperature than HMA but provides the same level of workability (Bayazit et al., 2014). WMA technology reduces greenhouse gas emission and energy consumption with a lower production temperature of asphalt mixtures (Jamshidi et al., 2012). Caro et al., (2012) also showed a reduction in energy consumption during the production of the mixtures due to the lower mixing and compaction temperature. However, moisture damage is one of the main concern of WMA (Li et al., 2015).

There are three categories of WMA technologies such as foaming, organic additives, and chemical additives. A fourth category, referred to as hybrids, utilizes combinations of any of other categories (West et al., 2014). According to Bayazit et al., (2014), addition of waxes may slightly increase the moisture susceptibility of asphalt mixtures. Meanwhile, there are investigations stated an improvement in moisture sensitivity when using waxes in decreasing the construction temperatures (Gandhi, 2008). Numerical reports have shown the inconsistency of moisture susceptibility of WMA thus increases the challenges to produce WMA.

2.3 Mineral Filler

According to Malaysian Public Works Department (PWD, 2008), Standard Specification for Road Works, mineral filler shall be incorporated as part of the combined aggregate gradation. It shall be of finely divided mineral matter of hydrated lime. The total amount of hydrated lime shall be approximately 2% by weight of the combined aggregates. However, when hydrated lime is not available, ordinary Portland cement shall be used as an alternative.

Filler refer to aggregate particles that are finer than 75 µm in size. Although the filler particles are small in size, it is reported that filler has a significant effect on the characteristics and performance of asphalt mixture (Zulkati et al., 2012).

Mineral fillers are added to asphalt mixture serve the purpose to fill voids in the mixture. Mahan (2013) says that the mineral fillers have a dual purpose when added to asphalt mixtures. First, the mineral filler was mixed with asphalt binder to form mastic and contributes to improving stiffening of the asphalt mixture. Secondly, the mineral fillers are used to fill the voids between aggregates, accordingly increasing the density and strength of the compacted asphalt mixture. The mineral filler also influences the optimum binder content (OBC) in the bituminous mixtures through the increases of the surface area of mineral particles (Muniandy et al., 2013).

2.3.1 Hydrated Lime

Hydrated lime (HL) is mainly composed of calcium hydroxide $Ca(OH)_2$. It is obtained by hydrating quicklime which is produced by burning limestone of very high purity at 900˚C in dedicated kilns (Lesueur et al., 2012).

Lime has been used in hot mix asphalt (HMA) to reduce moisture sensitivity and stripping since 1910 (National Lime Association, 2017). It is found that modifications made to HMA with hydrated lime will add years to pavement’s life. These modifications can reduce stripping, rutting, cracking, and aging (National Lime Association, 2017). According to Lesueur et al., (2013), HL is “active filler” that also reduces the chemical aging of the bitumen and stiffens the mastic. Lesueur et al., (2013) show HL modifies the surface properties of aggregate to allow roughness surface which is more favorable to bitumen adhesion. HL also reacts chemically with the acids of bitumen, which contribute to improving aging resistance and adhesion of mix.

Meanwhile, Al-Tameemi et al., (2015) justify HL has a wide range of particle size distribution and proportion. Its large particles can act as filler to enhance the stiffness of the asphaltic mixture, while small particles can increase the asphalt viscosity to improve its cohesion. It also found that the modified asphalt mixture has improved the ability to resist permanent deformation, fatigue failure, thermal cracking, and moisture susceptibility.

2.3.2 Ordinary Portland Cement

Ordinary Portland Cement (OPC) is essentially calcium silicate cement which is produced by firing to partial fusion at a temperature of approximately 1500˚C (Sadeeq et al., 2014). OPC is used to prevent the stripping of the binder from the previously dried aggregate (Wahed and Rashwan, 2016). Furthermore, Wahed and Rashwan (2016) also stated that OPC enhancing the coating process of wet aggregate with bitumen.

OPC also show a very significant effect on mix stability which addition of 1% produced increases of 250%-300% compared to untreated specimens (Oruc et al., 2006). Oruc et al., 2006 also stated that when specimens without OPC immersed in water after stability tests disintegrated after 24 hours. Whereas, cement treated specimens has no deteriorated. Besides that, utilization of OPC added to the aggregate at the time the asphalt emulsion was combined, the mixes cured faster, and more resilient modulus (Mr) developed rapidly (Dulaimi et al., 2015). The addition of OPC in asphalt mixture also results in enhancing the stiffness modulus, permanent deformation resistance and fatigue strength of the emulsified mixes (Dulaimi et al., 2015).

2.3.3 Fly Ash

According to Kolisetty (2013), fly ash is a mineral by-product of coal combustion in thermal power plants. It is generally finer than cement and consists of a mostly spherical glassy compound of complex composition. ASTM 618 defines two classes of fly ash which are Class F and Class C. Class F originate from the burning of anthracite or bituminous coal, while Class C originate from the burning of lignite or subbituminous coal. Class F fly ash is pozzolanic, with little or no cementing value alone and Class C fly ash has self-cementing properties. The use of Class F usually results in slower strength development, but the use of Class C fly ash may even enhance early strength development.

Likitlersuang and Chompoorat (2016) also provide a series of data showing fly ash were beneficial in terms of improved strength, stiffness and stripping resistance of asphalt mixture. Sobolev et al., (2013) show that the use of fly ash in bitumen materials is attractive as it not only improve the performance but also reduces costs and environmental impacts.

2.4 Warm Mix Asphalt Technology

Warm mix asphalt (WMA) is a technology that allows significant lowering of the production and paving temperature of hot mix asphalt (HMA). By reducing the viscosity of asphalt binder, some WMA technologies can achieve a temperature of 100˚C or even lower without compromising the performance of asphalt. There are three WMA technologies categorized under foaming, organic or wax technologies and chemical additives (Zaumanis and Haritonovs, 2010).

2.4.1 Foaming Technology

Foaming technologies can be achieved by injected small amounts of cold water into the hot binder or directly added in the asphalt mixing chamber. The water creates a volume expansion of the binder that results in asphalt foam. The foaming action has improved the coating and workability of the asphalt mixture (Goh, 2012).

2.4.1.1. Aspha-Min

Aspha-min is a product of Eurovia Services GmbH, Bottrop, Germany. It is a manufactured synthetic zeolite which has been hydro thermally crystallized. The percentage of water held internally by the zeolite is 21% by mass and is released in the temperature range 85˚C - 182˚C. Aspha-Min is added in the mix simultaneously with the binder to create a very fine water spray. This release of water creates a volume expansion of the binder that results in asphalt foam and allows increased workability and aggregate coating at lower temperatures. According to the manufacturer, adding Aspha-Min at a rate of 0.3% by mass of the mix, it can result in a potential 12˚C reduction in typical HMA production temperatures. This reduction in temperature is reported to lead to a 30% reduction in fuel energy consumption (Federal Highway Administration, 2016).

2.4.1.2. Advera

Advera WMA is a product of PQ Corporation, Malvem, Pa. It is a manufactured synthetic zeolite which has 18 – 21% of its mass as water entrapped in its crystalline structure. This water is released at temperatures above 98˚C when the zeolite contacts the heated asphalt binder. It creates foaming in binder thus allows improvement in workability of the asphalt mixture with the increases of the binder volume. The