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ESTABLISHMENT OF A RESILIENT MODULUS TEST FOR EVALUATING REDUCED SIZE ASPHALT MIXTURE

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By

FRANCIS XAVIER A/L ANTHONEY

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

August 2019

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DEDICATION

Especially to my beloved parents…

Father
(Late Mr. S. Anthoney PPN, PMC, PJK, PPA, PSS, PKL)

Mother
(Madam I. Soo Saimmah @ Mariaselvam)

Special thanks to

Brothers
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Last but not least to my other half…

My beloved wife
(Ms. G. Vijayalachumi)

My beloved son
(Junior F. Daniel)

Thanks for the support, encouragement, guidance, advice, patience and faith…

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

ESTABLISHMENT OF A RESILIENT MODULUS TEST FOR EVALUATING REDUCED SIZE ASPHALT MIXTURE

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FRANCIS XAVIER A/L ANTHONEY

August 2019

Chairman : Professor Ir. Ratnasamy Muniandy, PhD
Faculty : Engineering

The distress in asphalt pavements, which includes fatigue, rutting, and low-temperature cracking, were all related to the elastic modulus of the asphalt layer. The elastic modulus of the asphalt layer is interchangeably used with resilient modulus. Besides, the elastic modulus of asphalt concrete is a design variable for asphalt pavement structural design when the elastic-layer system theory is employed. However, in the most commonly used asphalt concrete design methods such as the Marshall, Hveem, and Superpave methods, the elastic modulus is not used as a control variable. Thus, the elastic modulus of asphalt concrete might not have studied.

In current practice, the performance evaluation of existing flexible pavements has become a priority issue for many highway maintenance engineers. To make appropriate rehabilitation and management decisions, the engineers most often rely on efficient methods for the determination of the strength of pavement layers. This statement underlined that the resilient modulus is a crucial parameter to be identified and should be used in pavement design. The resilient modulus of asphalt mixtures is typically measured using the indirect tension test procedure in compliance with the ASTM D4123 standard.

The scope of this study is limited to the binder with penetration grade 80/100 Hot Mix Asphalt (HMA) pavements. The coarse and fine aggregate, together with mineral fillers conforming to the gradation envelope for asphalt concrete with a nominal aggregate size of 14mm from JKR Standard Specification for roadworks reference JKR/SPJ/2008-S4 has been adopted. The small size of asphalt mixture specimens was prepared and studied in the laboratory, and the effects of different loading and pulse widths applied to 225 numbers of samples were investigated. In the mix design stage, a total of 20 numbers of samples were prepared using Marshall Mix Design, which

consists of 15 compacted samples and the remaining five loose samples for Theoretical Maximum Density (TMD).

The standard requirement is that the prepared specimens for the tests should have a minimum height of the sample over its diameter ratio of 0.4. Generally, specimens used in the tests are either a nominal 100mm or 150mm in diameter, with a minimum thickness over a diameter ratio of 0.4. However, 100 mm diameter core specimens taken from site wearing courses with thicknesses from 40 mm to 50 mm most often do not fulfil the minimum ratio of 0.4 after the samples are trimmed for testing. Since there was not an option, part of the binder courses was trimmed to make up the requirement. This tends to result in an inaccurate assessment of the resilient modulus values of the samples. As such, a new procedure was developed to test specimens smaller than 100 mm in diameter. This may minimize the material volume requirement from the field and also for the fabrication of smaller samples in the laboratory. Based on the available thickness of wearing course or overlay, the appropriate sizes were determined. For a two-layer system, 56.3 mm diameter was significantly necessary, while a 37.5 mm diameter was observed to be appropriate for a three-layer system. Resilient modulus test using reduced size specimens of 56.3mm and 37.5mm in diameter has excellent potential for application in the industry.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENETAPAN UJIAN MODULUS RESILIN UNTUK MENILAI SAIZ CAMPURAN ASFALT YANG DIKURANGKAN

Oleh

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Kerosakan turapan asfalt, seperti kelelahan, rutting dan keretakan akibat suhu rendah, adalah berkaitan dengan modulus elastik lapisan asfalt. Modulus elastik daripada lapisan asfalt adalah sama dengan modulus resilen Di samping itu, modulus elastik daripada konkrit asfalt adalah pembolehubah reka bentuk untuk reka bentuk struktur turapan aspalt apabila teori sistem lapisan elastik digunakan. Walau bagaimanapun, dalam kaedah rekabentuk konkrit asfalt yang digunakan kebiasaanya seperti kaedah Marshall, Hveem, dan Superpave, modulus elastik tidak digunakan sebagai pemboleh ubah dalam kaedah rekabentuk ini. Oleh itu, modulus elastik kepada konkrit asfalt tidak dapat dipelajari.

Dalam amalan semasa, penilaian prestasi turapan fleksibel merupakan isu utama dalam kejuruteraan penyelenggaraan lebuh raya. Untuk membuat keputusan pemulihan dan pengurusan yang sesuai, jurutera harus bergantung pada kaedah yang cekap untuk menentukan keadaan struktur turapan. Kenyataan ini menggariskan bahawa modulus resilin adalah parameter yang penting untuk dikenalpasti dan seharusnya digunakan dalam rekaan turapan. Modulus resilin kepada campuran asfalt kebiasaanya diukur menggunakan prosedur ujian tegangan tidak langsung yang mematuhi standard ASTM D4123.

Skop kajian ini terhad kepada pengikat dengan pengetatan gred 80/100 Hot Mix Asphalt (HMA). Agregat kasar dan halus bersama-sama dengan pengisi mineral yang memenuhi sampul surat penggredan untuk konkrit asfalt dengan saiz agregat nominal 14mm dari Spesifikasi Standard JKR untuk rujukan jalan raya JKR / SPJ / 2008-S4 telah diterima pakai. Sampel kecil campuran campuran asfalt telah disediakan dan dikaji di makmal dan kesan beban dan lebar pulse yang berbeza diselidiki terhadap 225 sampel. Dalam peringkat reka bentuk campuran, sejumlah 20 sampel telah

disediakan menggunakan Marshall Mix Design yang terdiri daripada 15 sampel yang dipadatkan dan baki 5 sampel longgar untuk Ketumpatan Maksimum Teori (TMD).

Standard keperluan adalah spesimen-spesimen untuk ujuan seharusnya mempunyai ratio ketinggian dengan diameter 0.4. Biasanya, spesimen adalah sama dengan nominal 100mm atau 150mm dengan ketebalan minimum melebihi nisbah diameter 0.4. Bagaimanapun, sampel teras berdiameter 100mm tipikal dengan ketebalan 40mm hingga 50mm yang diambil dari tapak paling kerap tidak memenuhi nisbah minimum 0.4 selepas sampel dipotong untuk ujian. Oleh kerana tiada pilihan lain, bahagian kepada pengikat kasar telah dipotong untuk memenuhi keperluan. Ini telah menyebabkan ketidaktepatan pengukuran kepada nilai modulus resilin sampel-sampel. Oleh itu, satu prosedur baru dibangunkan untuk menguji spesimen yang lebih kecil daripada diameter 100mm. Ini akan meminimakan keperluan isipadu bahan dari lapangan dan juga untuk fabrikasi sampel-sampel yang lebih kecil dalam makmal. Berdasarkan ketebalan yang ada kepada kursus pemakaian atau pertindanan, saiz-saiz yang lebih padan telah ditentukan. Untuk sistem dua lapisan, diameter 56.3mm adalah signifikan sesuai manakala diameter 37.5mm yang telah diperhatikan lebih sesuai kepada sistem tiga lapisan. Ujian modulus resilin yang menggunakan saiz spesimen-spesimen yang telah dikurangkan iaitu 56.3mm dan 37.5mm mempunyai potensi yang besar untuk diaplikasikan dalam industri.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment on the requirement for the degree of Doctor of Philosophy. The members of the supervisory committee were as follows:

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

A.I	Asphalt Institute
AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Content
ACV	Aggregate Crushing Value
ACWC	Asphaltic Concrete Wearing Course
AIV	Aggregate Impact Value
AS	Australian Standard
ASTM	American Society for Testing and Materials
BS	British Standard
CNC	Computer Numerical Control
DGA	Dense Graded Asphalt
EM	Elastic Modulus
F	Force
FWD	Falling Weight Deflectometer
GPa	Gigapascals
HMA	Hot Mix Asphalt
JKR	Jabatan Kerja Raya
KM	Kilometer
Kpa	Kilopascal
KRPSB	Kajang Rock Premix Sdn. Bhd.
LA	Los Angeles
LPDS	Layer-Parallel Direct Shear
MATTA	Material Testing Apparatus

Mpa	Megapascal
M_R	Resilient Modulus
N	Newton
OAC	Optimum Asphalt Content
OGA	Open Graded Asphalt
Pa.s	Pascal-second
RAP	Recycled Asphalt Pavement
SGA	Superpave Gyratory Compactor
SMA	Stone Mastic Asphalt
SN	Serial Number
SSD	Saturated Surface Dry
SUPERPAVE	Superior Performing Asphalt Pavements
TMD	Theoretical Maximum Density
UPM	Universiti Putra Malaysia
VFA	Void Filled with Asphalt
VMA	Void in Mineral Aggregate
VTM	Void in Total Mix

CHAPTER 1

INTRODUCTION

1.1 General Background

Resilient modulus (M_R) remains on being the primary design element for the asphalt pavement system (Arshad et al., 2018). Precise learning of the resilient modulus of asphalt layer materials permits the establishment of how the asphalt system will react to vehicle loadings. Resilient modulus is utilized to describe asphalt pavement materials under loading forms that will not fail the asphalt pavement system. Asphalt pavements were designed to undertake different types of design axles (single, couple, tridem, and quadrem) load applications. By changing layer depth and stiffness, the asphalt pavement system could be designed to take the designed axle load applications throughout its life span (Hamzah, 2009).

The distresses of asphalt pavement, which includes fatigue, rutting and low-temperature cracking, are related to the elastic modulus of the asphalt layer, which is interchangeably used with resilient modulus. Also, the elastic modulus of asphalt concrete is a design variable for asphalt pavement structural design when the elastic-layer system theory is employed. However, in the most commonly used asphalt concrete design methods (the Marshall, Hveem, and Superpave methods), the elastic modulus is not used as a control variable. Therefore, these design methods do not ensure that the desired elastic modulus of asphalt concrete (Mohammad, Herath, & Huang, 2003).

The common test method used to establish the resilient modulus of bituminous blends is indirect tension test (Fedrigo et al., 2018 and Islam et al., 2015). This test is carried out by applying a compressive load with a haversine or other appropriate waveform. The loads should be applied vertically in the vertical diametral plane of a diametral asphalt pavement sample. The subsequent horizontal deformation of the sample is calculated and, with a presumed Poisson's ratio or measured with the calculated recoverable vertical and horizontal deformations, is utilized to compute resilient modulus values.

A metal loading strip with the bold-shape surface having a radius of arc shape, which is equivalent to the nominal radius of the test sample is essential to apply load to the sample. The test samples will typically be either a nominal size of 100mm or 150 mm in diameter. The load strip edges were smoothened by grinding to eradicate the sharp edge so that it does not cut the specimen throughout the testing process.

Commonly, it is portrayed as the proportion of applied deviation stress to recoverable strain. When a specific load is applied to a material, contact stress will take place. The said stress is equivalent to the load divided by the loading strip's contact area.

Basically, stress gives a technique for load regularizing and area for testing and design purposes. At the point when a tyre load is applied directly to the asphalt pavement surface, areas under the wheel path load will experience dissimilar stages of stress based on their thickness from the surface and distance from the applied vehicle loading.

There are plenty of elements influencing the resilient modulus of asphalt pavement when subjected to indirect tension test. These comprise of geometric components of the test samples, stones maximum nominal size, the load waveforms and pulse lengths applied to the samples, the preset strain values obtained while carrying out the test, and the compaction type.

1.2 Problem Statement

An overlay is the placement of added layers of asphalt pavement to rectify functional or structural insufficiencies of current pavement and may or may not consist of milling (Design & Section, 2018). Pavement conservation is a cost-effective method to prolong the life cycle of installing pavement increased safety and meets the motorist's expectations. There are numerous methods for conserving asphalt roads, including chip seals, slurry seals, micro-surfacing, fog seals, crack treatment and thin asphalt overlays (Babashamsi et al., 2015). Among the methods stated, thin asphalt overlays are most applicable.

Nicholls et al., explained that the thin asphalt overlays are the treatment for bituminous surface layer on the pavements and this technique proposedly to enhances the structural properties by strengthening the pavement and reducing the deformability. This technique involved the installation of the asphalt layer, approximately 38.1 mm or less (1.5 inches or less) in thickness, and the material layer consisted of finer aggregates (a nominal maximum aggregate size of 12.5 mm or less likely to the aggregates in typical Superpave asphalt mixes (Im, Kim, & Nsengiyumva, 2015). This technique was widely applied by roadway maintenance agencies as this technique offers several advantages such as cost-effective and extend the life span and improve the structure of pavement (Zeki and Al-Busaltan, 2019). However, limited literature for the application of this technique on the management of roadway in Malaysia opens a new opportunity for the contribution of this study.

Smaller sample geometries have been gaining attention in current years to allow the testing of as-built pavement layers. Performance testing of asphalt mixtures permits for assessment of the material properties, which can be merged into pavement performance prediction models. The Asphalt Mixture Performance Tester (AMPT) was established to permit for routine testing of asphalt mixes using laboratory made-up diametral test samples, 100 mm (4 in) diameter and 150 mm (6 in). However, forensic testing for the pavement layers only allowed more than 4 inches thickness; thus, opens a new niche area to study (Castorena & Kim, 2017).

The evolution of the hot mix asphalt (HMA) design method was encouraged by the reported distress, caused by higher traffic volumes and automotive axle loading on highways (Kayedi et al., 2016, and Rosli et al.,2018). Previous research has been carried out to assess the possibility of applying the 100mm diameter sample for testing HMA. Laboratory produced HMA specimens were compacted at 150mm and 100mm diameters using the Gyratory Compaction Machine. The researchers suggested the use of 150mm diameter samples for the design of large stone asphalt mixes. A later study was conducted to evaluate the possibility of using 100mm diameter specimens for Superpave design purposes (Jackson & Czor, 2003). Conversely, no study was carried out on a smaller diameter than 100mm diameter for thin overlay pavements.

The thickness over diameter ratio less than 0.4 generally limits assessment of core samples taken from overlay or wearing courses due to the fact that the thickness of it is often between 40mm and 50mm. This makes it inappropriate to run tests such as resilient modulus since the thickness over diameter after trimming falls below 0.4 ratio.

Therefore, this project was focused on the preparation of the test subjects, which had a ratio of thickness over diameter of minimum 0.4. The thickness over a diameter of more than 0.4 or minimum requirement of 0.4, was established by ASTM D4123 testing standard. The reason is the stress distribution in the X - direction and Y - direction must have sufficient area and volume coverage.

1.3 Objectives of the Study

The main objective of this study is to establish the resilient modulus test evaluation process using reduced size diametral specimens using laboratory equipment with some modification to the current equipment. The extended objectives are as follows:

i. To determine the aggregate gradation range and asphalt binder properties
ii. To formulate hot mix asphalt mixture for the fabrication of 100mm, 56.3mm and 37.5mm diameter core specimens
ii. To design and fabricate appropriate core bits and jigs for sample preparation and testing
iii. To establish resilient modulus prediction models for overlay core assessment using reduced size specimens
iv. To validate the newly established prediction models with new sets of fabricated reduced size samples

1.4 Scope and Limitations

This research is mainly focused on laboratory-based assessment to establish the resilient modulus values of 100mm diameter (control specimen), 56.3mm diameter and 37.5mm diameter asphalt blend samples. This research also restricted to only bitumen with penetration grade of 80/100 Hot Mix Asphalt (HMA) asphalts. The coarse and fine aggregate together with mineral filler conforming to the gradation envelope for asphaltic concrete with a nominal aggregate size of 14mm from JKR Standard Specification (JKR/SPJ/2008-S4) for roadworks reference. The reduced size of asphalt blend samples was made and examined in the laboratory. The impact of various load and pulse width was carried out on a total of 225 numbers of laboratory prepared specimens. In the mix design phase, a sum of 20 numbers of the specimens was made using Marshall Mix Design method which comprised of fifteen (15) numbers of the compacted specimen while the rest of the five (5) numbers of specimens were uncompacted mixtures for Theoretical Maximum Density (TMD).

From cross-sectional areas calculation, data for curvature and jig contact area for proposed sample diameter indicated that the standard jig testing 100mm diameter was not suitable for this study as the proposed sample diameters were lower than 100mm, which were 56.3mm and 37.5mm. Furthermore, the stress distribution will be different, thus obstruct the obtained result. Therefore, the suitable jig curvature was fabricated via the Computer Numerical Control (CNC) machine to meet this study's requirement.

1.5 Hypotheses

The objective of this study is to establish the Resilient Modulus test evaluation process using reduced size diametral specimens.

To date, the current pavement industry in Malaysia, experienced difficulties in evaluating the resilient modulus value for thin overlay pavement designs because, it may not meet the required value of 0.4 ratios, for the thickness of the sample over diameter ratio. Thus, there is no standard procedure available to measure this kind of ratio as the design pavement currently only achieved lower than 50 mm.

In normal practice, core samples with a standard diameter of 100mm and 150mm with a minimum thickness of 40mm and 60mm have been used as conventional test samples. In this study, the core diameter of 37.5mm, 56.3mm and 100mm (control) samples were proposed. These diameters were chosen since they meet the requirements of thickness over a diameter of the samples to have a ratio of 0.4. Thus, it is supposed that the decreased diameter samples could easily achieve the 0.4 ratio to a certain extent and still have an adequate cross-sectional area that is crucial to furnish the steadfast resilient modulus values.

To establish the appropriate thickness and diameter of the samples, the aggregates must be appropriately sized before it could be used to prepare the asphalt mixes. Due to the consideration of the appropriate load, the other two parameters, which were pulse and temperature also proposed and controlled. These parameters should be included in this study since the small sample, has a lesser cross-sectional area compared to a bigger sized sample. In this study, the load between 350N ~ 1200N was established as well as the pulse range, which is set between 2000ms ~ 4000ms. The standard load and pulse used were 1200N and 3000ms. Tests for both 100mm and 150mm diameter samples were carried out at the temperature of 25°C. The calculated cross-sectional area for 100mm, 56.3mm and 37.5mm are 7853.98mm^2, 2489.47mm^2 and 1104.47mm^2. The curvature for the same samples was 12.795mm, 12.872mm and 13.020mm. The jig contact area for the three samples was 812.483mm^2, 289.620mm^2 and 195.300mm^2 respectively.

1.6 Overview of the Thesis

The study consists of five chapters. Chapter 1 outlines the importance of resilient modulus to pavement layers. Then it explains the objectives and derives the hypotheses of this study. Chapter 2 undertakes a systematic review of studies on resilient modulus by others. The methodology adopted in this study and the testing methods development is presented in detail in Chapter 3. Chapter 4 presents the results of the findings. Lastly, Chapter 5 presents the discussion and conclusion.

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BIODATA OF STUDENT

Francis Xavier Anthoney was born in Selangor, Malaysia. He graduated with Bachelors's Degree in Civil Engineering from the University of Malaya (UM), Kuala Lumpur, Malaysia, in August 2000. He worked in the consultation industry mainly in the construction of transportation infrastructure such as highways upon graduation. In March 2006, he successfully completed his studies in Master of Engineering in Highway and Transport Engineering at University Putra Malaysia (UPM). He also worked overseas as Chief Engineer at Dubai Metro Project in the year 2008. He registered as a Graduate Engineer with The Board of Engineers Malaysia (BEM). He is accepted as a Graduate Member to The Institution of Engineers, Malaysia (IEM). Currently, he is attached to Lingkaran Trans Kota Sdn. Bhd., (Concessionaire for Lebuhraya Damansara-Puchong) as a Manager. Currently he is in the final stage of his Ph.D. in Highway and Transport Engineering at University Putra Malaysia (UPM), which focuses on the pavement.

LIST OF PUBLICATIONS

Publications

Muniandy, R., Anthoney, F. X., Jakarni, F., and Hassim, S. ***Preliminary Investigation on Establishing a New Resilient Modulus Test Approach for Reduced Size Asphalt Mixture Samples Smaller Than 100 mm Diameter***. Published Under Journal of Traffic and Transportation Engineering 8 (2020) 93-105.

Muniandy, R., Anthoney, F. X., Hassim, S., and Hamid, H. ***Establishing a Resilient Modulus Test Protocol for Miniature Cylindrical Asphalt Mix Specimens***. Published Under Licence by IOP Ltd. Materials Science and Engineering, 512 (2019) 012058.

Anthoney, F. X., Muniandy, R., Hassim, S., and Jakarni, F. ***Determination of Resilient Modulus Parameter on Miniature Samples Using a Newly Developed Test Protocol***. In Proceeding of International Conference on Road and Airfield Pavement Technology 2019 (11^{th} ICPT 2019). 10-12 July 2019, Kuala Lumpur, Malaysia.

Anthoney, F. X., Muniandy, R., Hassim, S., and Hamid, H. ***An Overview of Resilient Modulus Test on Flexible Pavement Overlay***. In Proceeding of Global Civil Engineering Conference (GCEC2017). 26-28 July 2017, Kuala Lumpur, Malaysia.

Manuscripts Submitted for Publication

Muniandy, R., Anthoney, F. X., Hassim, S., and Hamid, H. ***Preliminary Investigation on Establishing a New Resilient Modulus Test Approach for Reduced Size Samples Smaller than 100mm Diameter***. Submitted to *Road Materials and Pavement Design*. Date of Submission on 21/10/2019.

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