UNIVERSITI PUTRA MALAYSIA

DENSITY RESILIENT-MODULUS CORRELATION IN STONE MASTIC ASPHALT MIXTURE USING AUTOMATED ROLLER COMPACTOR

EHSAN SOLEIMANI ZADEH

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By

EHSAN SOLEIMANI ZADEH

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Partial Requirements for the Degree of Master of Science

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DEDICATION

This thesis is dedicated to:

Whom their true love and support were behind my success

My dear parents

&

My beloved brother and sisters

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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Resilient or stiffness modulus (M_R) is the key property that has been utilized to characterize asphalt mixture and other structural properties for flexible pavement design. M_R is generally obtained by testing laboratory compacted samples which are compacted to a density similar to that achieved in the field under traffic. However, resilient modulus test has been considered as a complex, time-consuming, and expensive experiment. In addition, the poor simulation of field compaction by the present compaction methods may results in less accurate and unrealistic data for pavement design, especially in SMA mixtures. Hence, the main objective of this study was to develop correlation between density and resilient modulus properties of Stone Mastic Asphalt (SMA) slabs compacted using a newly developed roller compactor named Turamesin. Turamesin, which has proven to be capable of simulating field compaction conditions in the laboratory, is also able to produce laboratory samples with desired density and uniformly distributed properties. To come up with research objectives, total numbers of five slabs with different targeted level of air voids were prepared and core specimens were subjected to different tests of bulk density, air voids, resilient modulus (at 25°C and 40°C), Marshall stability, and flow. Statistical methods including regression analysis were then conducted and from the results, it was found that the stiffness properties of Turamesin compacted SMA slabs are directly affected by physical and volumetric properties of mixtures in terms of density and air voids. To correlate density with M_R at 25°C and 40°C, two different equations were developed. These findings then were employed to establish guideline on density-resilient modulus which is included with two main and two imaginary line, making possible to determine M_R of the mixture at any temperature of 25°C, 30°C, 35°C, and 40°C without need to conduct a complex, time-consuming, and expensive resilient modulus test.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

KORELASI MODULUS-KENYAL KETUMPATAN DALAM CAMPURAN STONE MASTIC ASPHALT MENGGUNAKAN PEMAMPAT GELEKAN AUTOMATIK

Oleh

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Kekenyalan ataupun modulus ketegaran (M_R) ialah suatu ciri penting yang telah digunakan untuk mencirikan campuran asphalt dan juga ciri-ciri struktur yang lain untuk rekaan turapan yang fleksibel. Secara lazim, M_R ialah didapati dengan menguji sampel yang dimampat dalam makmal yang telah dimampatkan sehingga tahap ketumpatan yang sama dengan keadaan sebenar lalulintas. Akan tetapi, ujian modulus kekenyalan disifatkan sebagai ujian yang kompleks, memakan masa yang lama, dan berkos tinggi. Selain itu, simulasi mampatan medan yang tidak utuh menggunakan kaedah mampatan pada waktu kini, mungkin akan menghasilkan data yang kurang jitu dan tidak realistik dalam rekaan turapan, terutamanya dalam campuran SMA. Maka objektif kajian ini ialah untuk mengembangkan korelasi di antara ketumpatan dan modulus kekenyalan kepingan Stone Mastic Asphalt (SMA)

yang dimampatkan pemampat giling yang dinamakan Turamesin. Turamesin, yang terbukti mampu mensimulasi keadaan mampatan terisi di dalam makmal, juga mampu menghasilkan sampel-sampel makmal yang mempunyai ketumpatan yang dikehendaki dan ciri-ciri taburan sekata. Untuk memenuhi objektif penyelidikan, sebanyak lima kepingan dengan sasaran rongga udara yang berbeza telah dibuat dan spesimen-spesimen teras telah menjalani beberapa ujian ketumpatan kontan, rongga udaramodulus kekenyalan (pada suhu 25°C dan 40°C), kestabilan Marshall, dan keberaliran. Kaedah analisis statistical termasuk analisis regression telah dijalankan, dan daripada hasil yang diperolehi, adalah ditemui bahawa ciri-ciri ketegaran sampel campuran SMA yang dimampatkan Turamesin diberi kesan daripada ciri-ciri fizikal dan volumetrik campuran, dari segi ketumpatan dan rongga-rongga udara. Untuk mengkorrelasi ketumpatan dengan M_R pada suhu 25^o dan 40^o C, dua persamaan yang berbeza telah dikembangkan. Penemuan-penemuan ini kemudiannya digunakan untuk menghasilkan garis panduan bagi modulus ketumpatan-kekenyalan yang disertakan dengan dua satah utama dan dua satah khayalan, memungkinkan pengenalpastian nilai M_R campuran pada sebarang suhu, 25°C, 30°C, 35°C, and 40°C tanpa memerlukan ujikaji modulus yang kompleks, memakan masa dan berkos tinggi.

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I certify that a Thesis Examination Committee has met on 28 April 2009 to conduct the final examination of Ehsan Soleimani Zadeh on his thesis entitled "Density Resilient-Modulus Correlation in Stone Mastic Asphalt Mixture Using Automated Roller Compactor" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

____

EHSAN SOLEIMANI ZADEH

Date**:** 16 June 2009

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Concrete
ANOVA	Analysis of Variance
ASTM	American Society for Testing and Materials
BS	British Standard
COV	Coefficient of Variation
HMA	Hot Mix Asphalt
ITSM	Indirect Tensile Stiffness Modulus
JMF	Job Mix Formula
LCPC	Laboratoire Central des Ponts et Chaussees
LVDT	Linear Variable Differential Transducer
MATTA	Material Testing Apparatus
NAPA	National Asphalt Pavement Association
OAC	Optimum Asphalt Content
RMSE	Root Mean Square Error
SGC	Superpave Gyratory Compactor
SLR	Simple Linear Regression
SMA	Stone Mastic Asphalt
SSD	Saturated Surface Dry
TMD	Theoretical Maximum Density
TRB	Transportation Research Board
UPM	Universiti Putra Malaysia
VFA	Voids Filled with Asphalt

VMA	Voids in Mineral Aggregates
VTM	Voids in Total Mix
M_R	Resilient Modulus
R^2	Coefficient of Determination
s	Sample Standard Deviation
$\overline{x}$	Sample Average

CHAPTER 1

INTRODUCTION

1.1 General Background

The provision of infrastructures of which road network plays a significant and fundamental role is essential in today's world of globalization to increase the nation's competitiveness across the region. In Malaysia, the road network forms the bloodline of the country's economic activities carrying about 96% of transported goods and passengers (Dato' Sri Prof. Ir. Dr. Judin Abdul Karim, 2008). The main and most important mode of transportation in Malaysia is mostly by road which is affected by country's geographical feature. The annual number of passengers transported by private cars and buses in 2003 is 1,836 million and 850 million persons, respectively. The share of road transport of passengers comprises 64.8% by private car and 30.0% by bus, as compared to 4.7% by rail transport and 0.5% by air transport (Ahmad & Azmi, 2008).

Malaysia with an entire land area of 330,252 km^2 is linked by 87,025 km of roads in 2007, which about 67,851 km is paved, and 19,174 km unpaved. Comparing this to the year 2002, there is an increase of about 20% on total road networks only during last five years (Economic Planing Unit, 2008). Since the formation of Malaysia in 1963, road development as one of the consequential elements for the extensive economic and social development of the country was included in subsequent 5-year national development plans. Figure 1.1 shows the growth in the expenditure on road development plans which is plotted from 1966 to 2005 (Ahmad & Azmi, 2008).

Together with development of road network, number of vehicle ownership has been increased dramatically, averaging 8% per annum from 7.7 million in 1996 to 12.8 million vehicles in 2003. This had caused into an increase in the number of road accidents from 189,109 cases in 1996 to 298,651 cases in 2003 (Isa, 2004). Due to this increase in road accidents, the need for safer, smoother, more comfortable, and lasting longer roads is greater than ever, which has led to demand for more durable, stronger and environmentally friendlier pavements, especially in terms of asphalt mixtures.

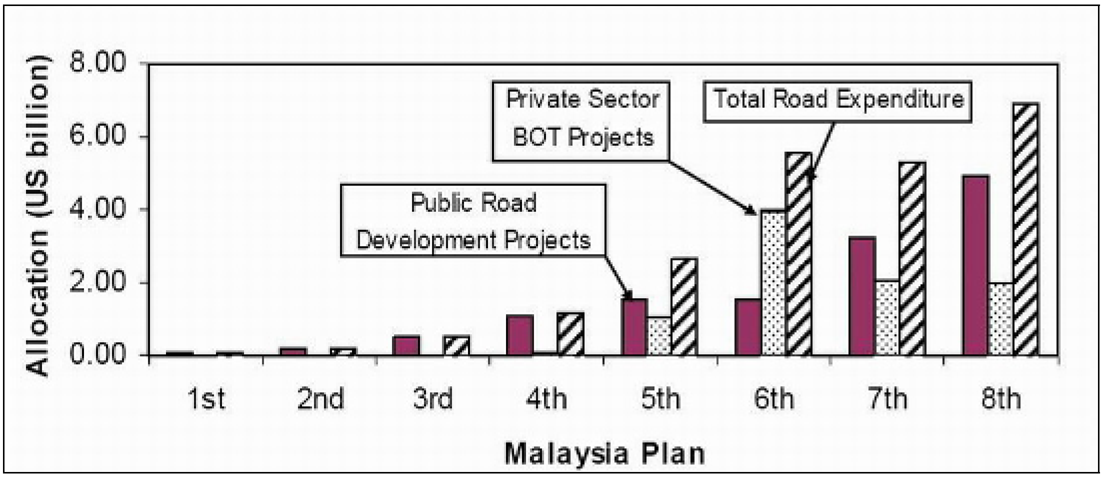

Figure 1.1. Expenditure on Road Development Plans in Malaysia, 1966-2005 (Source: Ahmad & Azmi, 2008)

As we are entering the new millennium, the global demands on transportation funding and highway network are greater than ever. These demands, together with increasing public expectations for safety, quality, and performance, call for highway authorities to come up with new and efficient techniques in designing and constructing of roads. During recent years, philosophy in flexible pavement design has been gradually changed from the more empirical method to the mechanistic approach based on elastic theory (Mamlouk & Sarofim, 1988). The "AASHTO

Mechanistic-Empirical Pavement Design Guide" (M-E Design Guide) was released in 2004 with the goal of improving the existing pavement design procedures. The M-E Design Guide transitions from the existing empirical-based pavement design procedures to mechanistic-empirical based procedures (Massachusetts Highway Department, 2006).

Elastic properties of asphalt pavements are widely used for pavement evaluation and maintenance. Design methods which are based upon elastic theory need the elastic properties of pavement materials as input. Resilient modulus measured in the indirect tensile mode according to ASTM D-4123 "Standard Test Method for Indirect Tension Test for Resilient Modulus of Bituminous Mixtures" is the most well known form of stress-strain measurement used to evaluate elastic properties. Also, resilient modulus is used as an index for evaluation of stripping, fatigue, and low temperature cracking of asphalt mixtures (Brown & Foo, 1989).

Pavement mix design procedures are usually derived from laboratory experiments, since laboratory conditions are less time consuming and easy to control. However, laboratory experiments should be able to simulate to a high degree the conditions in the field, especially in term of compaction procedures of asphalt mixtures (Khan et al., 1998). Laboratory compaction is an important part of asphalt mix design and the method of compaction significantly affects engineering properties of Asphalt mixture such as bulk density and air voids. The amount of voids in an asphalt mixture is probably the single most important factor that affects performance throughout the life of an asphalt pavement. The voids are primarily controlled by asphalt content, compactive effort during construction, and additional compaction under traffic. The voids in an asphalt mixture are directly related to density; thus, density must be closely controlled to ensure that the voids stay within an acceptable range (Brown, 1990).

Due to its performance and excellent resistance to deformation, Stone Mastic Asphalt (SMA) is rapidly getting to be used all over the world and it seems that almost all of the road agencies are changing over to it. SMA is a gap-graded mix, which contains a high concentration of coarse aggregate, thereby maximizing stone-to-stone contact in the mix and providing an efficient network for load distribution. The coarse aggregate particles are held together by rich mastic of mineral filler, fiber, and polymer in a thick asphalt film. Based on a combination of Georgia Department of Transportation and European experience, SMA has proven to have the following intrinsic benefits (Georgia Department of Transportation, 2003):

- 30-40% less rutting than standard mixes;
- Three to five times greater fatigue life in laboratory experiments;
- 30-40% longer service life (in Europe); and
- Lower annualized cost.

The performance of asphalt concrete (AC) pavements is a function of different parameters such as traffic loading and volume, the environment, the engineering properties of underlying layers, and the characteristics of asphalt mixtures. Understanding the behavior of the AC mixtures under different environmental conditions and loading is important for efficient design and maintenance of pavements. Inappropriate characterization of the asphalt layer may lead to under-