



**UNIVERSITI PUTRA MALAYSIA**

**EVALUATION OF PROPERTIES OF STONE MASTIC ASPHALT SLAB  
PRODUCED USING A NEW ROTARY COMPACTOR**

**MOHAMMAD SAEED POURTAHMASB**

**FK 2009 65**



**EVALUATION OF PROPERTIES OF STONE MASTIC ASPHALT SLAB  
PRODUCED USING A NEW ROTARY COMPACTOR**

**BY**

**MOHAMMAD SAEED POURTAHMASB**

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

**March 2009**



**Dedicated to my beloved family:**

**Dad, Mom**

**&**

**My Sister**



Abstract of thesis presented to the Senate of University Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

**EVALUATION OF PROPERTIES OF STONE MASTIC ASPHALT SLAB  
PRODUCED USING A NEW ROTARY COMPACTOR**

By

**Mohammad Saeed Pourtahmasb**

**March 2009**

**Supervisor: Associate Professor Ratnasamy Muniandy, PhD**

**Faculty: Engineering**

Recent laboratory studies have shown that the compaction can highly affect the performance of Stone Mastic Asphalt (SMA) mixtures. California kneading compactors, Gyrotory compactors and Marshall impact compactors are being used as SMA compactors in the mix design methods. But according to the performance of the SMA compacted specimens, none of them could simulate the field compaction one hundred percent. Breaking down of the aggregates during compaction is one of the most extensive problems in road mixtures and if that becomes prevalent, the mixture may not meet the minimum VMA (void in mineral aggregate) and VCA (void in coarse aggregate) requirements.

In this study, the newly developed Rotary compactor was introduced as a new equipment for laboratory compaction to reduce the previous laboratory compactor problems and to have better field simulation. Physical properties of materials such as



aggregates, bitumen and fiber have been considered as one of the objectives in this research. So the physical properties of the asphalt mixture materials were determined in accordance with relevant international standards such as ASTM, AASHTO and BS. The weight of required materials per each Rotary slab was approximately 130kg and Marshall mix design was selected as a mix design method to measure the Optimum Asphalt Content (OAC) and based on the Asphalt Institute method the OAC was obtained 6%. A total of three SMA slabs were prepared in accordance with UPM in-house protocol for Rotary compactor and 88 core specimens with 100mm diameters and 8 core specimens with 200mm diameter were cored out and subjected to performance tests.

SMA core specimens with 100mm diameters were tested for density, air void, stability, flow, resilient modulus, indirect tensile strength (IDT), moisture induced damage and fatigue. Also, 8 core specimens with 200mm diameters were subjected to Loaded Wheel Tracking (LWT) test to measure the rut resistance level of the Rotary SMA specimens. Finally, the performance test results were tabulated and analyzed. The entire analysis indicated that the results can be accepted in terms of performance of the SMA core specimens compacted using the newly developed Rotary compactor. It can be concluded that Rotary compactor can be used as a new heavy duty laboratory compactor.



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

**PENILAIAN CIRI-CIRI KEPINGAN STONE MASTIC ASPHALT YANG  
DIHASILKAN MELALUI CIPTAAN TERBARU MESIN PEMADAT  
BERPUTAR**

Oleh

**Mohammad Saeed Pourtahmasb**

**Marc 2009**

**Penyelia: Prof. Madya Ratnasamy Muniandy, PhD**

**Fakulti: Kejuruteraan**

Kajian di makmal kebelakangan ini menunjukkan bahawa pemadatan adalah sangat mempengaruhi prestasi campuran Stone Mastic Asphalt (SMA). Pemadat menguli California, pemadat Gyratory dan pemadat hentaman Marshall adalah antara yang biasa digunakan sebagai pemadat untuk campuran SMA. Akan tetapi berdasarkan prestasi spesimen SMA yang telah dipadatkan, hasilnya tiada pun spesimen yang menyerupai seratus peratus seperti pemadatan di tapak.

Pemecahan agregat sewaktu pemadatan adalah salah satu masalah yang rumit untuk adunan SMA dan jika masalah ini berterusan, campuran tidak akan dapat mencapai



tahap minima untuk kandungan rongga di dalam agregat mineral (VMA) dan kandungan rongga di dalam agregat kasar.

Dalam kajian ini, sejenis mesin pemadat Rotary yang baru direka telah diperkenalkan sebagai alat pemadatan di makmal untuk mengurangkan masalah-masalah yang dialami jika menggunakan mesin-mesin pemadat yang biasa digunakan sebelum ini. Pemadat Rotary ini juga bertujuan untuk meningkatkan kesamaan spesimen di makmal seperti pemadatan di tapak. Sifat-sifat fizikal bahan-bahan campuran seperti agregat, bitumen dan fiber telah diambil kira sebagai salah satu subjek dalam kajian ini.

Sifat-sifat tersebut ditentukan berdasarkan standard antarabangsa seperti ASTM, AASHTO dan BS. Berat bahan-bahan yang diperlukan untuk setiap slab Rotary adalah dianggarkan 130kg dan campuran Marshall telah dipilih untuk menentukan kandungan asfalt yang optimum (OAC) dan berdasarkan kaedah dari Asphalt Institute, kandungan OAC yang diperolehi adalah enam peratus. Sejumlah tiga slab SMA disediakan menurut protokol UPM untuk mesin pemadat Rotary, 88 spesimen berdiameter 100mm dan 8 spesimen berdiameter 200mm akan dijadikan subjek untuk ujian prestasi.

Spesimen SMA berdiameter 100mm telah diuji dengan ujian ketumpatan, ujian rongga udara, ujian kestabilan, ujian ketahanan modulus, ujian kekuatan tegangan tidak langsung (IDT), ujian kelembapan penyebab kerosakan dan ujian retakan kelemahan teraruh (*fatigue test*). Manakala lapan spesimen berdiameter 200mm akan diuji untuk ujian Loaded Wheel Tracking (LWT) untuk menguji paras *rut resistance*. Akhir sekali,

keputusan ujian prestasi dimasukkan kedalam jadual dan dianalisis. Analisis menunjukkan ujian-ujian prestasi spesimen SMA menggunakan mesin pemadat Rotary yang baru ini boleh diterima pakai. Dapat disimpulkan bahawa mesin pemadat Rotary boleh digunakan sebagai mesin pemadat yang baru untuk kegunaan di makmal supaya dapat menghasilkan simulasi spesimen seperti pemadatan di tapak.



## ACKNOWLEDGEMENTS

In the name of GOD, the Compassionate, the Merciful. I would like to kindly thank all those who helped me with their valuable support during my research to accomplish my master's thesis.

First I would like to thank my supervisor committee Assoc. Prof. Dr. Ratnasamy Muniandy and Assoc. Prof. Ir. Salihudin Hassim for giving me the opportunity to work under their supervision, which increased my knowledge of pavement engineering considerably and without their advice and support this study would not have been possible. I would also like to thank the Ministry of Science and Technology for providing the grant and supporting this project.

Last but not least, I appreciate my family, which I owe a big debt of gratitude to them for their full support during my entire life.



## APPROVAL SHEETS

I certify that an Examination Committee has met on **31.03.2009** to conduct the final examination of **Mohammad Saeed Pourtahmasb** on his Master of Science thesis entitled " **EVALUATION OF THE PROPERTIES OF STONE MASTIC ASPHALT SLABS PRODUCED USING A NEWLY DEVELOPED ROTARY COMPACTOR (ROTOCOM)**" in accordance with Unversiti Pertanian Malaysia (HIGHER Degree) Act 1980 and Universiti Pertanian Malaysia (High Degree) Regulation 1981. The committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

**Husaini Bin. Omar, PhD**

Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

**Abdul Halim Bin Ghazali, PhD**

Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Internal Examiner)

**Hussain Bin. Hamid, PhD**

Senior Lecturer  
Faculty of Engineering  
Universiti Putra Malaysia  
(Internal Examiner)

**Meor Othman Hamzah, PhD**

Professor  
Faculty of Engineering  
Universiti Sains Malaysia  
(External Examiner)

---

**Bujang Kim Huat, PhD**

Professor and Deputy Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date:



This thesis submitted to the senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee are as follows:

**Ratnasamy Muniandy, PhD**

Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

**Salihudin b. Hassim**

Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

---

**HASANAH MOHD. GHAZALI, PhD**

Professor and Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date: 8 June 2009



## **DECLARATION**

I hereby declare that this thesis is based on my original work except for quotation and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Putra Malaysia or other institutions.

---

**MOHAMMAD SAEED POURTAHMASB**

Date: 14 May 2009



## TABLE OF CONTENTS

	<b>Page</b>
<b>DEDICATION</b>	ii
<b>ABSTRACT</b>	iii
<b>ABSTRAK</b>	v
<b>ACKNOWLEDGEMENTS</b>	viii
<b>APPROVAL SHEETS</b>	ix
<b>DECLARATION</b>	xi
<b>LIST OF TABLES</b>	xvi
<b>LIST OF FIGURES</b>	xviii
<b>LIST OF ABBREVIATIONS</b>	xxi

<b>CHAPTER</b>		<b>Page</b>
<b>1</b>	<b>INTRODUCTION</b>	<b>1</b>
	1.1 General Background	1
	1.2 Problem Statement	4
	1.3 Objectives of Study	5
	1.4 Scope and Limitations of the Study	5
<b>2</b>	<b>LITERATURE REVIEW</b>	<b>7</b>
	2.1 Asphalt Mix Design Method	7
	2.1.1 Aggregate Selection and Testing	8
	2.1.2 Asphalt Selection and Testing	9
	2.2 Asphalt Mix Compaction	10
	2.2.1 California Kneading Compactor (Hveem Mix Design Method)	11
	2.2.2 Marshall Impact Compactor (Marshall Mix Design Method)	14
	2.2.3 Superpave Gyrotory Shear Compactor	16
	2.3 Other Types of Laboratory Compactors	20
	2.3.1 Rolling Wheel Compactor	20
	2.3.2 Turamesin	22
	2.3.3 Rotary Compactor	23
	2.4 Field Compaction	25



2.5	Stone Mastic Asphalt (SMA) and characterizations	29
2.6	Advantages and Disadvantages of SMA Mixtures	32
2.7	Performance Tests of Asphalt Mixtures	33
2.7.1	Bulk Density and Air Voids	33
2.7.2	Marshal Stability and Flow	34
2.7.3	Resilient Modulus	35
2.7.4	Moisture Induced Damage	37
2.7.5	Indirect Tensile Strength (IDT)	39
2.7.6	Fatigue Cracking	40
2.7.7	Rutting and Loaded Wheel Tracking (LWT)	44
2.8	Summary	48
<b>3</b>	<b>METHODOLOGY</b>	<b>49</b>
3.1	Introduction	49
3.2	Physical Properties of Materials	50
3.2.1	Los Angeles Abrasion Test	53
3.2.2	Aggregate Impact Value Test	54
3.2.3	Aggregate Crushing Value (ACV)	55
3.2.4	Ten Percent Fines	55
3.2.5	Polished Stone Value (PSV)	56
3.2.6	Soundness Test	58
3.2.7	Flakiness and Elongation Index Test	59
3.2.8	Angularity Number	61
3.2.9	Specific Gravity of Aggregate	62
3.2.10	Aggregate Gradation	63
3.2.11	Asphalt Testing	65
3.2.12	Fiber Selection And Testing	67
3.3	Marshall Mix Design	69
3.3.1	Marshall Sample Preparation	70
3.3.2	Theoretical Maximum Density (TMD)	72
3.3.3	Density and Void Analysis	74
3.3.4	Marshall Stability and Flow	75
3.3.5	Determination of Optimum Asphalt Content (OAC)	76



3.4	Preparation of Rotary SMA Slabs and Core Specimens	78
	3.4.1 Rotary SMA Slab Preparation	79
	3.4.2 Rotary Slabs, Cutting and Coring Procedures	81
3.5	Performance Tests on SMA Core Specimens	84
	3.5.1 Resilient Modulus Test	85
	3.5.2 Moisture Induced Damage Test	86
	3.5.3 Indirect Tensile Strength Test (IDT)	87
	3.5.4 Repeated Load Indirect Tensile Test (Fatigue Test)	88
	3.5.5 Loaded Wheel Tracking (LWT) Test	89
<b>4</b>	<b>TEST RESULTS AND DISCUSSION</b>	<b>92</b>
4.1	Introduction	92
4.2	Aggregate Test Results And Analysis	93
	4.2.1 Los Angeles Abrasion	93
	4.2.2 Aggregate Impact Value	94
	4.2.3 Aggregate Crushing Value	94
	4.2.4 Ten Percent Fines	95
	4.2.5 Polished Stone Value	97
	4.2.6 Soundness	98
	4.2.7 Flakiness and Elongation Index	99
	4.2.8 Aggregate Specific Gravity	100
	4.2.9 Angularity Number	100
	4.2.10 Summary of Aggregate	102
	4.2.11 Aggregate Gradation	102
4.3	Asphalt Test Results and Discussion	104
	4.3.1 Penetration	104
	4.3.2 Softening Point	104
	4.3.3 Flash and Fire Point	105
	4.3.4 Viscosity	105
	4.3.5 Summary of Asphalt Test Results	106
4.4	Cellulose Fiber Test Results	106
4.5	Determination of Optimum Asphalt Content (OAC)	108



4.6	Performance Test Results and Analysis	113
4.6.1	Bulk Density and Air Void Results and Analysis	114
4.6.2	Marshal Stability and Flow Results and Analysis	118
4.6.3	Resilient Modulus Results and Analysis	121
4.6.4	Moisture Induced Damage Results and Analysis	124
4.6.5	Indirect Tensile Strength (IDT) Results and Analysis	126
4.6.6	Fatigue Results and Analysis	127
4.6.7	Loaded Wheel Tracking Results and Analysis	130
4.7	Comparative Analysis of Performance Test Variation between Rotary SMA Core Specimens and Typical SMA Marshall Specimens	133
<b>5</b>	<b>CONCLUSION AND RECOMMENDATIONS</b>	<b>141</b>
5.1	Conclusion	142
5.2	Recommendations	144
	<b>LIST OF REFERENCES</b>	<b>145</b>
	<b>APPENDICES</b>	<b>153</b>
	<b>BIODATA OF STUDENT</b>	<b>195</b>





## LIST OF TABLES

Table		Page
2.1	AASHTO MP8 Stone Mastic Asphalt (SMA) Aggregate Quality Requirement	9
2.2	Summary of Stability, Flow, Air Voids and Bulk Density Test Results for Laboratory and Field Specimens	20
2.3	Typical Aggregate Gradation for Different Surfacing	31
3.1	In-house Protocol for Rotary Slab Compaction	78
3.2	Laboratory Test Plan and Performance Test Standards	84
3.3	Repeated Load Indirect Tensile Test Setup	89
4.1	Los Angeles Abrasion	93
4.2	Aggregate Impact Value	94
4.3	Aggregate Crushing Value	95
4.4	Ten Percent Fines	95
4.5	Recalculated Ten Percent Fines	96
4.6	PSV Results	97
4.7	PSV Control Samples Results	97
4.8	Soundness Test	98
4.9	Flakiness Index	99
4.10	Elongation Index	99
4.11	Aggregate Specific Gravity	100



4.12	Angularity Number	101
4.13	Summary of Aggregate Test Results	102
4.14	Percentage of Passing, Desired Aggregate Gradation	103
4.15	Penetration	104
4.16	Softening Point	104
4.17	Flash and Fire Point	105
4.18	Asphalt Viscosity	105
4.19	Summary of Asphalt Test Results	106
4.20	Motor Oil Drain Down	107
4.21	Density, Stability and Flow	109
4.22	Optimum Asphalt Content (OAC)	112
4.23	Performance Tests and Required Specimens	113
4.24	Average of Density and Air Voids	114
4.25	Marshall Stability and Flow	119
4.26	Resilient Modulus	122
4.27	Moisture Induced Damage Specimen Selection and Test Results	124
4.28	IDT	126
4.29	Fatigue	128
4.30	Loaded Wheel Tracking	131
4.31	Rotary and Marshall Compactor Performance Test Results	134



## LIST OF FIGURES

<b>Figure</b>		<b>Page</b>
2.1	California Kneading Compactor	12
2.2	Marshall Impact Compactor	15
2.3	Gyratory Shear Compactor	18
2.4	European Standard Rolling Asphalt Compactor	21
2.5	Turamesin	23
2.6	The New Rotary Compactor Setup	24
2.7	Pavement Durability versus Air Voids	25
2.8	Static Steel-Wheel Roller	26
2.9	Pneumatic-Tire Roller	27
2.10	Vibratory Compactor	28
2.11	Stone Mastic Asphalt (SMA) and Dense Graded Asphalt (DGA)	30
2.12	Schematic Section of IDT Specimen	40
2.13	Schematic and Actual Fatigue Cracking	43
2.14	Rutting under the Wheel path	45
2.15	Loaded Wheel Tracking (LWT) Devices	47
3.1	Summary of Methodology	51
3.2	Experimental Design	52
3.3	LA Abrasion Apparatus	53



3.4	Aggregate Impact Test Apparatus	54
3.5	PSV and Skid Resistance Test Devices	57
3.6	Flakiness Test Plate	60
3.7	Typical SMA Aggregate Gradation	64
3.8	Fiber Grinding	68
3.9	Marshall Sample Preparation Procedure	71
3.10	Rice Method Procedure	73
3.11	Marshall Stability and Flow Tests	77
3.12	Well-Mix Asphalt Mixture and Temperature Drop Prevention	80
3.13	Rotary SMA Slab	81
3.14	Rotary SMA Slabs Labeling	82
3.15	Cutting, Labeling and Coring Procedures	83
3.16	Core Specimens from SMA Slabs	85
3.17	Resilient Modulus Test Setup	86
3.18	Indirect Tensile Strength (IDT)	88
3.19	Loaded Wheel Tracking (LWT) Test	90
4.1	Desired Aggregate Gradation	103
4.2	Fiber Particle Size Distribution	108
4.3	Bulk Density versus Percentage of Asphalt content	110
4.4	Stability versus Percentage of Asphalt Content	111
4.5	Voids in Total Mix (VTM) versus Percentage of Asphalt Content	112
4.6	First Slab Density Values	115



4.7	First Slab Air Void Values	115
4.8	Second Slab Density Values	116
4.9	Second Slab Air Void Values	117
4.10	Marshall Stability	120
4.11	Flow Test	120
4.12	Resilient Modulus	123
4.13	Moisture Induced Damage	125
4.14	IDT versus Air Voids	127
4.15	Average of Permanent Strain per Each Quadrant	129
4.16	Trend of Rut Depth versus Time	132
4.17	Variation of Bulk Density Test Results between Marshall and Rotary compactor	135
4.18	Variation of Air Void Test Results between Marshall and Rotary compactor	135
4.19	Variation of Marshall Stability Test Results between Marshall and Rotary compactor	136
4.20	Variation of Flow Test Results between Marshall and Rotary compactor	136
4.21	Variation of Resilient Modulus Test Results between Marshall and Rotary compactor	137
4.22	Variation of Tensile Strength Ratio Test Results between Marshall and Rotary compactor	137
4.23	Variation of IDT Test Results between Marshall and Rotary compactor	138
4.24	Variation of Fatigue Test Results between Marshall and Rotary compactor	138
4.25	Effect of Rotary and Marshall Compactors on Aggregate Degradation	139



## LIST OF ABBREVIATIONS / NOTATIONS / GLOSSARY OF TERMS

AASTO	American Association of State Highway and Transportation Officials
ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
ASTM	American Society for Testing and Materials
BS	British Standard
DGA	Dense Graded Asphalt
HMA	Hot Mix Asphalt
IDT	Indirect Tensile Strength
LVDT	Linear Variable Differential Transducer
LWT	Loaded Wheel Tracking
MATTA	Material Testing Apparatus
NAPA	National Asphalt Pavement Association
OAC	Optimum Asphalt Content
OGA	Open Graded Asphalt
PG	Performance Grade
PSV	Polished Stone Value
SGC	Superpave Gyratory Compactor
SHRP	Strategic Highway Research Program
SMA	Stone Mastic Asphalt



SSD	Saturated Surface Dry
TMD	Theoretical Maximum Density
TSR	Tensile Strength Ratio
UPM	University Putra Malaysia
VFA	Voids Field with Asphalt
VMA	Voids in Mineral Aggregates
VPM	Vibrations Per Minute
VTM	Voids in Total Mix



## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 General Background**

Stone mastic asphalt was developed in Germany in the 1960's and widely used throughout the world as a preferred asphalt surfacing. Stone Mastic Asphalt (SMA) provides a deformation resistant, durable surfacing material, suitable for heavily trafficked roads.

In recent years, the need for providing a safe and efficient road system has been a cause of concern to the Malaysian government. Road accident statistics indicate a marked increase in fatalities on Malaysian roads. The major reasons for building new expressways in Malaysia are the increasing number of vehicles along federal routes, the opening of major ports and airports in Malaysia, and the increasing population in major cities and towns of Malaysia.

The Civil Engineering Department of University Putra Malaysia (UPM) is one of the pioneer organizations in highway and transportation research and many studies have been carried out on flexible pavement. Stone Mastic Asphalt research work in UPM started in late 1994 with the Ministry of Science and Technology grant to develop SMA for Malaysian roads.





SMA has a high coarse aggregate content that interlocks to form a stone skeleton that resists permanent deformation. The stone skeleton is filled with mastic of bitumen and filler to which fibers are added to provide adequate stability of bitumen and to prevent drainage of binder during transport and placement. Typical SMA composition consists of 70–80% coarse aggregate, 8–12% filler, 6–7% binder, and 0.3% fiber (Brown & Mallick., 1994).

Recent laboratory studies have shown that compaction can highly affect the performance of Stone Mastic Asphalt (SMA) mixtures. The goal of compaction is to achieve the optimum air void content and compressing the coated stones together by increasing the density of the mix to the considered level of compaction with a minimum change in the gradation and structure. Inappropriate compaction may draw the binder to the surface of SMA causing flushing of the surface and loss of texture or aggregate segregation.

California kneading compactor, Gyrotory compactor and Marshall Hammer are being used as SMA compactors due to mix design method. But according to the performance of the SMA compacted specimens, none of them could simulate the field compaction one hundred percent. Achieving consistency in compaction, both in the laboratory and on site is necessary if accurate correlation is to occur between laboratory performance and observed site behaviour. It has been demonstrated that differing laboratory compaction methods can produce volumetrically identical specimens but with widely varying mechanical performance (Alistair et al., 1999).