THE AGGREGATE DEGRADATION CHARACTERISTICS OF STONE MASTIC ASPHALT (SMA) MIXTURES

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"Dedicated to my beloved father, Mohd Akhir and mother, Musalmiah,
my sisters, Mafizah, Fadilah, Sakinah and Norazalia,
my brothers, Mohd Shahizan and Mohd Saifuddin,
and to a special person…
for their love, support and patience are awesome"

"Also not forgotten to all my colleagues,
Elizabeth, Zanariah, Masyitah, Nordiana and Norhidayah,
for their assistance and encouragements towards the success of this study"

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ABSTRACT

Stone Mastic Asphalt (SMA) mixtures are designed to have a high coarse aggregate content and stone-on-stone contact which results in more stress on the coarse aggregate particles during compaction and traffic loads. For that reason, aggregates tend to break down more in SMA mixtures than in conventional dense-graded mixtures. Aggregate degradation during compaction and traffic loading may cause changes in the original gradation and thus may also affect the volumetric parameters of SMA mixtures. The main objective of this study was to determine the degree of aggregates degradation in SMA mixtures due to compaction process. Aggregates with two Nominal Maximum Aggregates Size (NMAS) which designated as SMA14 and SMA20 were compacted using the effort of 50 blows of Marshall Hammer and 100 gyrations of Superpave Gyratory Compactor (SGC). The verified samples were then prepared and extracted using Centrifuge Method. The same procedure was also performed for the cored samples. The comparisons of gradation of cored samples with the laboratory samples were evaluated to examine the aggregate degradation with respect to different compaction efforts. The relationship between aggregate degradation and influencing factor such as compaction efforts, and volumetric properties were investigated. Aggregate degradation by the Marshall Hammer was found to be significantly higher than degradation by the SGC. Voids in mineral aggregate (VMA) of either compaction methods decrease or almost the same when aggregate degradation is not significant. SGC methods can be selected to represent the field roller that result in similar trend of aggregate degradation.

ABSTRAK

Campuran *Stone Mastic Asphalt* (SMA) direka bentuk untuk mempunyai kandungan aggregat kasar yang tinggi serta daya ikatan antara aggregat (*stone-on-stone contact*). Aktiviti pemadatan di tapak dan pembebanan lalu lintas akan memberikan tekanan terhadap partikel aggregat kasar tersebut. Oleh yang demikian, aggregat di dalam campuran SMA lebih cenderung untuk pecah berbanding campuran panas bergred tumpat biasa. Kesan ini menyebabkan perubahan penggredan asal aggregat dan akhirnya mempengaruhi parameter volumetrik campuran SMA. Objektif utama kajian ini ialah untuk menentukan tahap pecahan aggregat di dalam campuran SMA yang disebabkan oleh proses pemadatan di makmal. Dua saiz aggregat maksimum nominal (NMAS) yang direka bentuk sebagai SMA14 dan SMA20 telah dipadat dengan 50 hentakan menggunakan Tukul *Marshall* dan 100 putaran oleh *Superpave Gyratory Compactor* (SGC). Sampel-sampel yang telah direka bentuk pada kandungan bitumen optimum disediakan dan kemudiannya diekstrak dengan Kaedah Emparan. Prosedur sama turut dilakukan ke atas sampel tebukan dari tapak. Perbandingan penggredan di antara sampel tebukan dan makmal dinilai untuk menentukan pecahan aggregat terhadap kaedah pemadatan yang berlainan. Hubungan di antara tahap pecahan aggregat dan faktor-faktor yang mempengaruhi seperti jenis pemadatan, dan ciri-ciri volumetrik aggregat dikaji. Hentakan Tukul *Marshall* didapati memecahkan aggregat lebih banyak berbanding putaran oleh SGC. VMA bagi setiap kaedah pemadatan berkurang atau sama apabila pemecahan aggregat tidak ketara. Kaedah SGC dipilih untuk mewakili pemadat tapak kerana mempunyai ciri-ciri pemadatan yang sama seperti pemadat tapak.

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LIST OF ABBREVIATIONS/SYMBOLS

SMA	Stone Mastic Asphalt
NAPA	National Asphalt Pavement Association
SHRP	Strategic Highway Research Program
SGC	Superpave Gyratory Compactor
NMAS	Nominal Maximum Aggregate Size
SMA14	Stone Mastic Asphalt with Nominal Maximum Aggregate Size of 12.5mm
SMA20	Stone Mastic Asphalt with Nominal Maximum Aggregate Size of 19mm
HMA	Hot Mix Asphalt
FHWA	Federal Highway Administration
ESAL	Equivalent Standard Axle Load
LAAV	Los Angeles Abrasion Value
ASTM	American Society for Testing and Materials
JKR	Jabatan Kerja Raya
VIM	Voids in Mix
VMA	Voids in Mineral Aggregate
OBC	Optimum Bitumen Content
NCAT	National Center for Asphalt Technology
AASHTO	American Association of State Highway and Transportation Officials
SSD	Saturated-surface-dry
TMD	Theoretical Maximum Density
VFB	Voids Filled with Bitumen
G_{mb}	Bulk specififc gravity of compacted mix
G_{sb}	Combined bulk specific gravity of total aggregate
G_{mm}	Theoretical maximum density

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Stone Mastic Asphalt (SMA), sometimes called Stone Mastic Asphalt especially in Europe, is a gap-graded hot mix asphalt surfacing material (Pierce, 2000). SMA is an asphalt mixture initially developed in the 1980s in Europe as an impervious wearing surface to provide rut resistant and durable pavement surface layer. When SMA is first introduced in Europe, it is used in resisting the studded tires effects rather than other type of hot mix asphalt (Roberts, Kandhal and Brown, 1996).

SMA is designed to resist deformation particularly rutting and maximize durability by using as structural basis of stone-on-stone contact. SMA is characterized by its high stone content and the voids of the structural matrix are filled with high viscosity bituminous matrix. The high stone content of at least 70% ensures stone-on-stone contact after compaction. The required degree of matrix stiffness is achieved through the addition of crushed sand (Roberts, Kandhal and Brown, 1996).

Because the aggregates are all in contact, rut resistance depends on aggregate properties rather than asphalt binder properties. Since aggregates do not deform as much as asphalt binder under load, this stone-on-stone contact significantly reduces rutting. The SMA pavement offers other side benefits due to its high content of

coarse aggregate. SMA pavement surfaces are porous, thus reducing the tire/pavement noise level as well as water spray and glare (NAPA, 1999).

However, SMA is generally more expensive than a typical dense-graded HMA (about 20 - 25 percent) because it necessitates more durable aggregates, higher asphalt content and typically, a modified asphalt binder and fibers (NAPA, 1999). Durability was to be defined primarily through rutting and cracking measurements, but was also to include other types of pavement deterioration (Schimiedlin and Bischoff, 2002). In the right situations, it should be cost-effective because of its performing better than the standard asphaltic concrete pavements in some important areas, i.e., crack and distress generation thus increase rut resistance and improve durability.

The mixture also entails higher mixing temperatures to provide greater workability and longer mixing times at the plant due to the presence of modified binder or mineral fiber ensuring proper distribution of the mineral fiber or adequate coating of aggregates, and more intensive quality control at plant and on job site (Watson and Jared, 1995). Based on its performance in term of durability and long life service, the use of SMA is currently keep increasing in popularity among the road authorities and the asphalt industry.

1.2 Problem Statement

SMA mixtures are designed to have high coarse aggregate content and stone-to-stone contact which results in more stress on the coarse aggregate particles during compaction and heavy traffic loads. As a result, the aggregates tend to degrade in SMA mixtures than in conventional dense graded mixtures. Aggregate degradation during compaction and heavy traffic loading may cause changes in the original aggregate gradation, and thus may also affect the volumetric properties of SMA mixtures.

Most work to date on SMA has been with Marshall Compactor but some works needs to be done with a Gyratory Machine since the new SHRP gyratory will

eventually be used on SMA mixes. With the introduction of the Superpave system, it is now significant for the mix designer who endeavoring to design stiffer, more rut-resistant asphalt concrete pavements having the alternative of using the Superpave Gyratory Compactor (SGC) for SMA mixtures.

The application of SMA is still new in Malaysia therefore the contractors had little experience with this mixture at the time of construction. Since this study has been done previously, but there has been little research conducted to relate with Malaysia's condition. Thus there is a need to study and determine the aggregate degradation of SMA particularly experienced in Malaysia.

1.3 Objectives of the Study

The objectives of this study were:

a) to determine the degree of aggregate degradation in SMA mixtures during the compaction process produced by 100 gyrations of the SGC and 50-blow Marshall Hammer;
b) to determine the effect of the gradation changes on volumetric properties of compacted SMA mixtures; and
c) to compare the aggregate degradation of compacted samples experienced at field and laboratory.

1.4 Scope of the Study

The scope of the study focused on the effects of compaction methods and aggregate gradation affecting the aggregate degradation in SMA. The mixtures with the nominal maximum aggregate size (NMAS) of 12.5mm (designated as SMA14) and 19mm (designated as SMA20) were studied. In designing mixtures, total of 36 specimens were prepared using Marshall Compaction Method with three specimens

for each of bitumen content of 5.0%, 5.5%, 6.0%, 6.5%, and 7.0% by Marshall Hammer at compaction efforts of 50 blows per face.

The work done by NCAT (Brown and Mallick, 1994 and Brown *et al.*, 1997) indicated that 50 blows of the Marshall Hammer generated a density in SMA mixtures approximately equal to 100 gyrations of the SGC. With the 100 gyrations effort, total of 16 specimens were prepared using Superpave Compaction Method, with two specimens gyrating by SGC at three bitumen contents of 6.0%, 6.5% and 7.0%. As a conclusion, the total of 64 specimens was prepared including the 12 specimens were designed for binder draindown test purpose.

The aggregate degradation afterward was determined by comparing the changes in gradation of extracted aggregate with the original aggregate gradation. To achieve the objectives, the scope started with literature search and review on the information related to the aggregate degradation in Chapter 2 and extensive laboratory testing according to specified procedure was explained detail in Chapter 3 respectively.

1.5 Importance of the Study

This study was carried out to quantify and compare the amount of aggregate degradation for SMA mixtures produced by 100 gyrations of the SGC and 50-blow Marshall Hammer. This study can be a reference to evaluate other studies according to the two compactive effort performances in the pavement design. Contractors from developing country such as Malaysia may have problem using SMA mix because of lack of experience since this mix is considered as new mix for road pavement compared to standard asphaltic concrete. This type of information would provide valuable information to agencies who desire to construct SMA pavements.

REFERENCES

American Association of State Highway and Transportation Officials. (2001). *Practice for Superpave Volumetric Design for Hot Mix Asphalt (HMA).* Washington D.C. AASHTO PP28-1.

American Association of State Highway and Transportation Officials. (2000). *Determination of Draindown Characteristics in Uncompacted Asphalt Mixtures.* Washington D.C. AASHTO T305.

American Association of State Highway and Transportation Officials (2000). *Preparing and Determining the Density of Hot-Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor*. Washington, D. C., AASHTO T-312.

American Society for Testing and Materials. (1992). *Standard Method for Sieve Analysis for Fine and Coarse Aggregate.* Philadelphia, ASTM C 136.

American Society for Testing and Materials. (1992). *Standard Test Method for Materials Finer than 75-μm (No. 200) Sieve in Mineral Aggregates by Washing.* Philadelphia, ASTM C 117.

American Society for Testing and Materials. (1992). *Standard Test Method for Specific Gravity and Absorption of Coarse Aggregate.* Philadelphia, ASTM C 127.

American Society for Testing and Materials. (1992). *Standard Test Method for Specific Gravity and Absorption of Fine Aggregate.* Philadelphia, ASTM C 128.

American Society for Testing and Materials. (1992). *Standard Test Method for Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens.* Philadelphia, ASTM D 2726.

American Society for Testing and Materials. (1992). *Standard Test Method for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures.* Philadelphia, ASTM D 2041.

American Society for Testing and Materials. (1992). *Standard Test Method for Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus.* Philadelphia, ASTM D 1559.

American Society for Testing and Materials. (1992). *Standard Test Method for Quantitative Extraction of Bitumen from Bituminous Paving Mixtures.* Philadelphia, ASTM D 2172.

Atkins, H. N. (2003). *Highway Materials, Soils and Concretes.* Fourth Edition. Upper Saddle River, New Jersey: Prentice Hall.

Balqis binti Abu Bakar (2006). *Kajian Kebolehtelapan Campuran Poros di Makmal*. Universiti Teknologi Malaysia: Degree Project Report.

Brown, E. R. and Haddock, J. E. (1997). A Method to Ensure Stone-on-stone Contact in Stone Matrix Asphalt Paving Mixtures. *NCAT Report No. 97-2*. National Center for Asphalt Technology, Auburn, Alabama.

Brown, E. R. and Mallick, R. B. (1994). Stone Matrix Asphalt Properties Related to Mixture Design. *NCAT Report No. 94-2*. National Center for Asphalt Technology, Auburn, Alabama.

Brown, E. R. and Manglorkar, H. (1993). Evaluation of Laboratory Properties of SMA Mixtures. *NCAT Report No. 93-5*. National Center for Asphalt Technology, Auburn, Alabama.

Brown, E. R., Haddock, J. E., Mallick, R. B., and Todd, A. L. (1997). Development of A Mixture Design Procedure for Stone Matrix Asphalt (SMA). *NCAT Report No. 97-3*. National Center for Asphalt Technology, Auburn, Alabama.

Buchanan, M. S. (2000). Evaluation of the Effect Flat and Elongated Particles on The Performance of Hot Mix Asphalt Mixes. *NCAT Report No. 00-03*. National Center for Asphalt Technology, Auburn, Alabama.

Garber, N. J. and Hoel, L. A. (2002). *Traffic and Highway Engineering.* Third Edition. United States of America: Brooks/Cole.

Hongbin, Xie and Watson, D. E. (2004). Lab Study on Degradation of SMA Mixtures. *83rd Annual Meeting of TRB.* Transportation Research Board, Washington, D. C

Huang, Y. H. (2004). *Pavement Analysis and Design.* Second Edition. Upper Saddle River, New Jersey: Prentice Hall.

Ibrahim, M. Asi (2005). *Laboratory Comparison Study for the Use of Stone Matrix Asphalt in Hot Weather Climates*. Hashemite University, Jordan; Elsevier.

Jabatan Kerja Raya (JKR) (2005). *Standard Specifications for Road Works*. Kuala Lumpur, Malaysia, JKR/SPJ/rev2005.

Kandhal, P. S., Parker, F. Jr. and Mallick, R. B. (1997). Aggregate Tests for Hot Mix Asphalt: State of the Practice. *NCAT Report No. 97-6.* National Center for Asphalt Technology, Auburn, Alabama.

Keunnen, T. (2003). Better Roads Magazine. *Stone Matrix Asphalt is Catching on in the U.S.* United States of America.

Mangan, D. and Butcher, M. (2004). Technical Note 16 Stone Mastic Asphalt. *Australian Roads Research Board*. Australia.

Moavenzadeh, F. and Goetz, W.H. (1963). Aggregate Degradation in Bituminous Mixtures. *Highway Research Record 24*. HRB. National Research Council. Washington D.C.

National Asphalt Pavement Association (NAPA). (1999). *Designing and Constructing SMA Mixtures: State-of-the-Practice*, QIP 122.

Pierce, L. M. (2000). Stone Matrix Asphalt. *WSDOT Report No. SR-524*. Washington State, United States of America.

Roberts, F. L., Kandhal, P. S. and Brown, E. R. (1996). *Hot Mix Asphalt Materials, Mixture Design and Construction.* NAPA Research and Education Foundation, Lanham, Maryland.

Robinson, R. and Thagesen, B. eds. (2004). *Road Engineering For Development.* Second Edition. New Fetter Lane, London: Spon Press.

Schimiedlin, R. B. and Bischoff, D. L. (2002). *Stone Matrix Asphalt The Wisconsin Experience*. Wisconsin Department of Transportation. Madison, United States of America.

Watson, D. E. and Jared, D. (1995). *Stone Matrix Asphalt: Georgia's Experience.* Georgia Department of Transportation. Georgia, United States of America.

Wu, Y., Parker, F. Jr. and Kandhal, K. (1998). Aggregate Toughness/Abrasion Resistance and Durability/Soundness Tests Related to Asphalt Concrete Performance in Pavements. *NCAT Report No. 98-4.* National Center for Asphalt Technology, Auburn, Alabama.