THE EFFECT OF AGGREGATE’S ANGULARITY ON ENGINEERING PROPERTIES AND PERFORMANCE OF POROUS ASPHALT

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A project report submitted in partial fulfillment of the
requirements for the award of the degree of
Master of Engineering (Civil - Transportation and Highway)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

JUNE 2013

DEDICATION…

A special dedication to my beloved mother, *Puan Hajah Hadiah binti Salleh* and also to my father, *Tuan Haji Ahmad Tarmuzi bin Haji Alem*, who often give encouragement, support and pray for my success during my Degree Master's study life.

Not to forget, my siblings, *Nazari, Noremilin, Norasmah and Norbaiti* for always giving me support and attention in any situation i had faced.

Not least, my beloved lecturers especially from the Transportation & Highway Engineering Program (MAP), classmates, and close friends who always being there during the time I need and their willingness to share knowledge, ideas, and opinion during study.

The sacrifice and loyalty that have been shown will not be forgotten until whenever. May all the said prayers will be getting blessings from Allah s.w.t. InsyaAllah...

Sincerely,
NADHIR BIN AHMAD TARMUZI

ACKNOWLEDGEMENTS

Bismillahirahmanirrahim…

Alhamdulillah, I am grateful to Allah s.w.t for the blessings and grace, I managed to complete the thesis entitled *"The Effect of Aggregate's Angularity on Engineering Properties and Performance of Porous Asphalt"* properly and successfully.

The utmost and heartiest gratitude to my supervisor, **Dr. Ramadhansyah Putra Jaya**, who always willing to share his invaluable and priceless knowledge and also giving constructive advice, and enthusiastic support to my research. I am also grateful to him for spending his precious time to view and evaluate the thesis.

A million thanks to all the technicians in the Transportation & Highway Laboratory, Faculty of Civil Engineering especially to Mr. Azman, Mr. Azri, Mr. Sahak, Mr. Muhammad Anwarrasyid, and Mrs. Rosmawati for their guidance and helps shown during the laboratory works.

A special thanks to my thesis teammates, **Thanwa Filza** and **Nurul Ain**, and also my laboratory mates, Muhammad Zul Hanif, Fung Lung Chang, Muhammad Naqiuddin, Mohd. Khairul Idham, Nur Hidayah, and Yuniza for their willingness to share precious knowledge, information, and support for accomplish this research.

Finally, I wish to express my acknowledgement to University Teknologi Malaysia for providing sufficient and adequate materials, equipments and conditions in completing this research.

ABSTRACT

Porous asphalt is a flexible pavement layer with high percent of interconnected air void and constructed using open-graded type of aggregate. Aggregate shape and surface texture plays a vital role in determining the engineering properties and performance of porous asphalt. Angular-shaped aggregate which has a clear defined fracture faces and sharp edges are preferable to be used in asphalt mixture since it encourages better interlocking structures within the aggregate's skeleton. This study was carried out to evaluate the effect of aggregate's angularity on engineering properties and performance of porous asphalt using a combination of conventional method and empirical Particle Index Test method. The term of engineering properties includes experimental works to determine the resilient modulus and stability while performance deals with the porosity and durability characteristics of porous asphalt due to variations in the Particle Index Number (I_a). From laboratory data analysis, it was found that angular particles delivers larger I_a number compared to those less-angular or non-angular particles. Significant improvement in the resilient modulus and stability properties has been obtained with application of angular-shaped aggregate. Angular particles also results in higher porosity of mixture but causes undesirable durability performance on porous asphalt against abrasion loss. Some improvements have been recommended to enhance the strength properties and performance of porous asphalt based on engineering explanation.

ABSTRAK

Asfalt poros merupakan sejenis lapisan turapan anjal dan mempunyai peratus liang udara yang tinggi dan berhubung antara satu sama lain serta dihasilkan menerusi penggunaan agregat jenis gred terbuka. Bentuk agregat serta tekstur permukaannya memainkan peranan yang penting dalam menentukan ciri-ciri kejuruteraan dan prestasi asfalt poros. Agregat bersegi serta mempunyai permukaan pecah yang jelas dan tajam bersifat lebih baik untuk digunakan di dalam campuran asfalt kerana ia menghasilkan struktur saling-hubung yang lebih baik dalam rangka agregat tersebut. Kajian ini telah dijalankan untuk menilai kesan kesegian agregat terhadap ciri kejuruteraan dan prestasi asfalt poros dengan menggunakan gabungan kaedah konvensional dan kaedah Ujian Indeks Partikel yang bersifat empirikal. Ciri kejuruteraan yang dinilai dalam kajian ini termasuklah eksperimen bagi menentukan modulus daya tahan dan kestabilan manakala ciri prestasi melibatkan penentuan tahap keliangan dan ketahanan asfalt poros disebabkan variasi dalam Nombor Indeks Partikel (I_a). Daripada analisis data makmal, didapati bahawa agregat bersegi menghasilkan nombor l_a yang lebih besar berbanding agregat tidak bersegi (berbentuk bulat dan sfera). Peningkatan yang ketara dalam nilai modulus daya tahan dan ciri kestabilan telah diperolehi menerusi aplikasi agregat berbentuk segi. Partikel bersegi juga menghasilkan ciri keliangan yang lebih tinggi pada asfalt poros tetapi mengakibatkan prestasi ketahanan yang kurang baik dalam rintangan terhadap daya lelasan. Justeru, beberapa penambahbaikan telah disyorkan bagi meningkatkan ciri-ciri kekuatan dan prestasi asfalt poros melalui penjelasan kejuruteraan.

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LIST OF ABBREVIATIONS

ASTM	-	American Standard on Testing Materials
AIV	-	Aggregate Impact Value
BS-EN	-	British Standard European Norm
HMA	-	Hot Mix Asphalt
JKR	-	Jabatan Kerja Raya (Public Works Department)
LAAV	-	Los Angeles Abrasion Value
OGFC	-	Open-graded Friction Course
PG	-	Performance Grade
SBS	-	Styrene-butadiene-styrene
SG	-	Specific Gravity
SSD	-	Saturated-surface-dry
TMD	-	Theoretical Maximum Density
UTM	-	Universal Testing Machine
WA	-	Water Absorption

LIST OF SYMBOLS

A	-	Average water absorption
B	-	Initial mass of binder in mix
D	-	Mass of binder drained
G	-	Average specific gravity (for either SSD, bulk, or oven-dry)
M	-	Total mass of mould, glass plate, and water
P	-	Maximum stability load
R	-	Mass of binder retained
W	-	Mass of an aggregate size fraction in one specimen
e	-	Correction factors for stability value
g	-	Gravity (9.81 m/s^{-2})
h	-	Amount of substitution by mass of aggregate size fraction
m	-	Percent of rounded / spherical aggregate used for substitution
n	-	Percent of remaining angular aggregate in sample
p	-	Probability
s	-	Oven-dry specific gravity of an aggregate size fraction
v	-	Volume of mould
δ	-	Total recoverable horizontal deformations
A_n	-	Water absorption of aggregate by size fraction
G_{mb}	-	Bulk specific gravity of specimen
G_{mm}	-	Theoretical maximum density of specimen
G_n	-	Average specific gravity of an aggregate size fraction
I_a	-	Particle IndexNumber
M_{SSD}	-	Mass of specimen in saturated-surface-dry condition
M_a	-	Mass of specimen in air (dry condition)
M_b	-	Mass of specimen and vacuum container in water (submerged)

M_a - Mass of specimen in air (dry condition)
M_b - Mass of specimen and vacuum container in water (submerged)
M_c - Mass of vacuum container in water
M_g - Mass of glass plate
M_m - Mass of mould
M_r - Resilient modulus
M_w - Mass of specimen in water (submerged)
M_{wm} - Mass of water filling mould
M_0 - Initial mass of specimen
M_1 - Final mass of specimen
M_{10} - Average mass of aggregate in mould tamped at 10 blows/layer
M_{50} - Average mass of aggregate in mould tamped at 50 blows/layer
P_n - Mass percentage of an aggregate by size fraction
V_a - Air voids
V_w - Specific volume of water
V_{10} - Air voids in aggregate sample tamped at 10 blows/layer
V_{50} - Air voids in aggregate sample tamped at 50 blows/layer
W_A - Mass of remaining angular aggregate in sample
W_R - Mass of rounded / spherical aggregate required for substitution

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CHAPTER 1

INTRODUCTION

1.1 Preface

Porous asphalt has been well-known for its advantages in improving skid resistance of pavement during rains, reducing splashing effects, preventing hydroplaning action on moving traffic, and producing lower riding noise (Liu and Cao, 2009). These criteria made exist due to high porosity possessed by porous asphalt which then allows for high drainage capability of surface run-off as well as better riding noise absorption.

The structure of porous asphalt can be distinguished from the conventional hot mix asphalt through large constituent of coarse aggregate and small amounts of fine aggregate together with mineral filler. According to Public Works Department of Malaysia (JKR, 2008), a compacted porous asphalt generally has a total percent of air voids between the range of 18 % to 25 % in which defined as relatively high if compared to the conventional dense-mixed asphalt (4 % to 5 % air voids).

The high voids content in porous asphalt have been enabled through the use of open-graded type of aggregate. Open gradation mainly consists of coarse aggregate with size dimension larger than 2.36 mm (No. 10 sieve) together with small percentage of fine aggregate (not more than 15 %) and also mineral filler not exceeding 5 % of the total aggregate weight (JKR, 2008). Hence, this subsequently produces a permeable layer of bituminous course with high percentage of interconnected air voids after compaction.

Porous asphalt is considered as a non-structural layer of flexible pavement. In the early years, porous asphalt was constructed with main purpose to overcome problems related to rainwater accumulation on pavement surface (Mallick *et al.*, 2004). However, limitations had occurred in terms of porous asphalt service-life due to unacceptable performance, lack in durability, and densification of layer under repetitive load actions (Mallick *et al.*, 2004; Chang and Pei, 2011). Therefore, porous asphalt should possess a sufficient strength and durability in bearing the external loads imposed by traffic. Several engineering properties owned by conventional asphalt such as resilient modulus and stability should also be evaluated for case of porous asphalt. This is important since porous asphalt forms the uppermost layer of flexible pavement, thus receiving loads from moving traffic in a direct way.

The engineering properties and performance of porous asphalt are greatly depends on several factors and one of them is related to the angularity in the shape of aggregate used. Angularity of an aggregate is described in terms of how many fracture face(s) it has to produce better interlocking in which increases the resistance against rutting and cracks formations (Huang *et al.*, 2009). Thus, angular shape aggregate is expected to play a critical role not only regarding to the engineering properties, but also in terms of its capability to maintain the performance criteria of porous asphalt.

1.2 Background of Study

Apart of the bitumen and additives, aggregate is the major constituent of materials which form most of the total volume and weight of any asphalt mixture. Due to this, the performance and behavior of asphalt mix in terms of its strength, durability, and workability are influenced by the properties of aggregate to be used. Therefore, determination on the basic properties of aggregate is essential to have an initial prediction on the characteristics of a compacted asphalt mixture.

Similarly in porous asphalt, attentions are given on mix design that capable of producing surface layer which has sufficient resistance against permanent deformation due to traffic loading. The resistance of porous asphalt is closely related to its engineering properties and performance criteria with aggregate shape and surface texture act as a major determinant to the mix behavior. In this study, an early assumption may state that porous asphalt with high constituent of angular-shaped aggregate should deliver better improvements on the engineering properties. Besides, variation in the particle's shape is estimated to affect the voids content of porous asphalt, thus influencing its porosity and durability performance.

1.3 Problem Statement

Considerably as a non-structural layer in flexible pavement, porous asphalt is greatly exposed for defects due to the imposed traffic loadings. Perhaps, high porosity owned by porous asphalt has also contributed to the severity of damage created. Pavement engineering properties such as resilient modulus and stability plays a vital role in ensuring the resistance of porous asphalt against permanent deformations and functional failure. This resistance performance is closely related to the physical shape of aggregate which has been the main constituent of materials used in forming asphalt layers.

Utilization of aggregate particles with undesirable shape might have a significant impact on the strength of porous asphalt against physical and functional defects. Therefore, porous asphalt has to have an adequate particle interlocking properties and at the same time capable of maintaining its porosity and durability characteristic. It has been a challenge in balancing these two criteria since aggregate's shape is quite a subjective parameter used in determining its influence on the engineering properties and performance of porous asphalt.

1.4 Aim and Objectives

The aim of this study is to investigate the effect of angular-shaped aggregate on engineering properties and performance of porous asphalt. The term of engineering properties is referred to the evaluation of resilient modulus and stability of porous asphalt while performance includes measurement on its porosity and durability against external forces. Among the objectives to achieve in this study are:

i. To study the correlation between angularity of aggregate with Particle Index Number (I_a).

ii. To determine the influence of Particle Index Number (I_a) on engineering properties and performance of porous asphalt.

1.5 Scope and Limitations of Study

This study focuses on the effect of aggregate shape on engineering properties and performance of porous asphalt. Therefore, several scope and limitations were needed to define clearly before commencing the experimental works. These include the following:

1. The asphalt mix tested was porous asphalt which uses open-graded type of aggregate gradation as provided in the Public Works Department (JKR) specification. In this study, Grading B type of porous asphalt mix has been selected.

2. The type of aggregate used was quarry crushed granite. However, special attention has been given on 14.0 mm and 10.0 mm particles with rounded or spherical shape and having less than two fracture faces. These particles were used for substitution in amount of 0 % to 100 % by fraction weight in the aggregate samples. Testing to determine the aggregate mechanical properties and shape index were following the British Standard European Norm (BS-EN) and American Standard on Testing Materials (ASTM).

3. The type of binder used is polymer-modified bitumen of PG 76. Testing to determine the design bitumen content was based on Cantabro Test and Binder Drain-Down Test as according to the JKR and ASTM standard.

4. Engineering properties measured in this study includes the resilient modulus and stability while performance relates to the porosity and durability resistance of porous asphalt. Testing procedure for the mentioned parameters was based on ASTM standard.

1.6 Significance of Study

Porous asphalt has been widely utilized especially in the European and North American countries, and also Japan. Constructions of porous asphalt are done in order to achieve specific goals or improvements on the physical performance of roads and highways. In Malaysia, the application of porous asphalt as permeable surface course of flexible pavement is still at unsatisfied level. Although so, it can be seen that the opportunity of using porous asphalt is quite spacious and even a necessity since our country receives a relatively high quantity of rainfall in a year (Abustan *et al.*, 2012). Perhaps, this condition exists due to limited research and study being conducted on the performance of porous asphalt under the influence of various factors.

Therefore, this study is intended to deliver better understanding on the improvements that are able to obtain through modification in terms of aggregate shape. This is essential in giving new ideas to the road engineers on how to manipulate particular properties of constituent materials in order to increase the usage value of porous asphalt and make suits of its application in local road construction. Further research could be performed to investigate the effect of other factors on the engineering properties and performance of porous asphalt. These factors may include method of construction applies, aggregate gradation and types, and even modification on the binder itself using polymers, fibers, and other possible materials.

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