PERFORMANCE OF DOUBLE LAYER POROUS ASPHALT INCORPORATING COCONUT SHELL AND COCONUT FIBRE

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ABSTRACT

The extensive use of coarse aggregate in construction has caused the reduction in the availability of the material. Thus, new sources of aggregates from environmental waste have been considered as coarse aggregate is one of the main components in highway industry. The abundance of coconut shells (CS) as waste material, which has contributed to environmental issues, has placed CS as a choice to replace coarse aggregate. This research focuses the partial replacement of CS in coarse aggregates and coconut fibres (CF) as additives in double layer porous asphalts (DLPA). CS and CF were soaked in 5wt% of Sodium Hydroxide (NaOH) solution before prior to mix in the asphalt mixture. CS has been used to substitute 0%, 5%, 10% and 15% of 5 mm of coarse aggregate, while 0%, 0.3% and 0.5% of CF were added into the asphalt mixtures respectively. The physical and chemical properties of CS were determined by various tests, namely FESEM, EdX, Aggregate Impact Value, Los Angeles Abrasion Value, and Specific Gravity and Water Absorption test. The asphalt mixtures were prepared using the Marshall Method and underwent the Cantabro and binder drain-down tests to determine optimum binder content for different replacement percentages of CS. The samples then underwent several tests such as the Marshall Stability, Resilient Modulus, Rutting Resistance test, Aging, Permeability and Sound Absorption tests to investigate the engineering properties. From the investigations, DLPA with 10% of CS replacement and 0.3% of CF additives showed improvement in the Resilient Modulus and Marshall Stability test by 55.9% and 8.54% respectively. On the other hand, 15% of CS replacement and 0.5% of CF additives showed the improvement in the Permeability test and Sound Absorption test by 10% and 5.6% respectively. The 10% of CS replacement without CF additives produced better results for the Aging Resilient Modulus test, which showed improvement 35.6%. These three mixture designs which showed better results in the properties tests went through Asphalt Pavement Analyzer together with the control sample. The results showed that the best mixture design in this study is obtained from mix design of 10% of CS replacement and 0.3% of CF additives. This concludes that CS is an alternative choice to partially replaced aggegrate, while CF is a good choice as additive in asphalt pavement.

ABSTRAK

Penggunaan batu baur secara meluas telah menyebabkan sumber bahan ini semakin berkurangan. Justeru, bahan baru dari sisa alam sekitar perlu dikaji untuk menggantikan batu baur kerana batu baur merupakan salah satu bahan yang penting dalam industri lebuhraya. Pembuangan tempurung kelapa (CS) yang menyumbang kepada isu alam sekitar telah menjadi pilihan utama bagi menggantikan bahan batu baur. Kajian ini memfokuskan penggunaan tempurung kelapa sebagai sebahagian bahan ganti kepada batu baur dan menggunakan serat kelapa sebagai bahan tambahan dalam asphalt berliang dua lapisan (DLPA). CS dan serat kelapa (CF) telah direndam dalam sodium hidroksida (NaOH) dalam 5wt% sebelum digunakan dalam campuran asphalt. CS telah digunakan untuk menngantikan 0%, 5% 10% dan 15% batu baur bersaiz 5 mm manakala 0%, 0.3% dan 0.5% CF ditambah ke dalam campuran asfalt. Sifat fizikal dan kimia tempurung dan serat kelapa telah ditentukan dengan beberapa ujian seperti FESEM, EdX, Ujian Nilai Hentaman Ageregat, Nilai Lelasan Los Angeles serta graviti tentu dan ujian serapan air. Campuran-campuran asfalt telah dihasilkan dengan kaedah *Marshall* dan telah menjalani ujian *Cantabro* dan *Binder drain-down* unuk menentukan kandungan optimum asfalt pengikat bagi perbezaan peratusan penggantian CS yang berbeza. Sampel-sampel tersebut kemudiannya telah menjalani beberapa ujian seperti kestabilan *Marshall*, modulus kebingkasan, ketahanan aluran, penuaan, kebolehtelapan dan serapan bunyi bagi mengkaji ciri-ciri kejuruteraannya. Daripada ujian-ujian tersebut, keputusan menunjukkan DLPA dengan penggantian 10% CS dan tambahan 0.3% CF telah dirawat menunjukkan keputusan penambahbaikan bagi ujian modulus kebingkasan dan kestabilan *Marshall* iaitu dengan 55.9% dan 8.54%. Manakala, sampel dengan penggantian 15% CS dan tamabahan 0.5% CF juga menunjukkan keputusan yang meningkat bagi ujian kebolehtelapan dan ujian serapan bunyi iaitu dengan 10% dan 5.6%. Penggantian 10% CS tanpa tambahan CF menunjukkan keputusan yang baik terhadap ujian penuaan modulus kebingkasan, dengan peningkatan 35.6%. Tiga rekabentuk campuran yang mendapat keputusan lebih baik daripada ujian ciri-ciri kejuruteraan bersama-sama sampel terkawal telah menjalani ujian Penganalisis Turapan asfalt. Keputusan tersebut menunjukkan rekabentuk campuran yang terbaik dalan kajian ini adalah penggantian 10% CS dan tambahan 0.3% CF. Kesimpulannya, CS adalah satu pilihan yang sesuai untuk menggantikan sebahagian batu baur manakala CF sesuai sebagai additif dalam turapan asfalt.

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LIST OF ABBREVIATIONS

OGFC	Open Graded Friction Course
DLPA	Double Layer Porous Asphalt
HMA	Hot Mix Asphalt
CS	Coconut Shell
CF	Coconut Fibre
NMAS	Nominal Maximum Aggregate Size
NaOH	Sodium Hydroxide
DBC	Design Binder Content
OBC	Optimum Bitumen Content
NaOCl	Sodium Hypochlorite
JKR	Public Works Department of Malaysia
AAPA	Australian Asphalt Pavement Association
MMC	Metal matrix composites
POS	Palm Oil Shells
XRD	X-Ray Diffraction
SEM	Scanning Electron Microscopy
EdX	Energy dispersion X-ray Spectroscopy
BET	Brunauer–Emmett–Teller
XRF	X-ray spectrometer
PSV	Polished Stone Value
ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
FI	Flakiness Index
EI	Elongation Index
AIV	Aggregate Impact Value
AASHTO	American Association of State Highway and Transportation Officials

SSD	Surface Saturated Dry
SMA	Stone Matrix Asphalt
LAAV	Los Angeles Abrasion Value

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CHAPTER 1

INTRODUCTION

1.1 Background of problem

Porous asphalt was introduced in the United States in 1950s. It began through experimentation with a seal coat treatment, by which the aggregates were diffused and rolled lightly into the layer of bitumen. It was introduced to drain water from a pavement's surface to help improve skid resistance and reduce tyre noise levels [1].

Porous asphalt can help in improving traffic safety, especially during rainy days as it has a drainage system that reduces hydroplaning potential and enhances skid resistance properties under high speeds. Besides that, porous asphalt can help in resisting permanent deformation [2].

In 1991, porous asphalt, also known as open graded courses (OGFCs), was introduced in Malaysia. It drains water easier than conventional asphalt, reduces hydroplaning potential and has better skid resistance properties under high speed usage. It is also known as "Drain asphalt" in France, Popcorn Mix in the United States of America and whispering asphalt in Germany [3].

However, double layer porous asphalt (DLPA) was first introduced in the 1990s by European countries [4]. Some countries such as Italy, Netherlands Germany, and Denmark have investigated two layer porous asphalts for further phase developments. This design can combine the noise reduction properties of the finer porous mix at the top layer and the drainage effects of a coarse surface and the coarse aggregate sizes in the bottom layer [5]. DLPA normally has finer aggregates at the top layer and coarser aggregates in the bottom layer as shown in Figure 1.1.

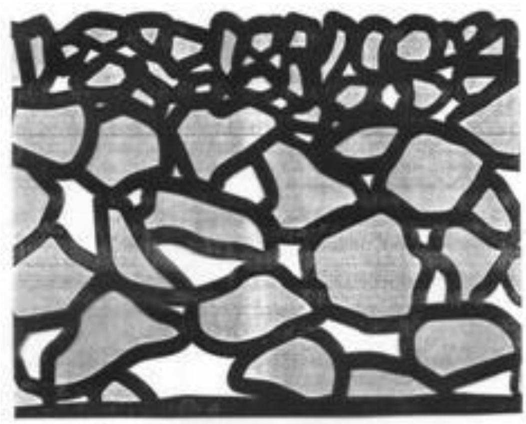

Figure 1.1 Schematic diagram of a DLPA [6, 7]

1.2 State of the Problem

Based on the information provided by the Institute of Asphalt Technology [8], the UK is paved with around 95% of asphalt mixtures and large quantities of aggregate are needed for construction and maintenance. About 20 million tonnes of aggregate were consumed and around 26 million tonnes of hot mix asphalt (HMA) were used in construction [9]. Besides that, the Highways Agency in England uses about 15 million tonnes of aggregate per year to manage trunk roads and motorways [10, 11].

With the increasing exploitation of natural aggregates, the restrictions of natural sources are concerning and environmental wastes have been introduced to replace natural sources in order to reduce the landfill cost and protect the environment from the possible effects of pollution.

Waste materials such as scrap tires, clinkers and coconut shells can be used to replace coarse or fine aggregates in the asphalt pavement. Besides that, the cost of disposing the waste material is prohibitive and the wastes usually take up 10 to 30% of landfill sites around the world for demolition [11-14]. Waste materials that are used as aggregate replacements in roadways can reduce the usage of landfill sites for demolition.

On the other hand, although porous asphalt has its advantages, it still has many disadvantages such as clogging, ravelling and short service life. Ravelling refers to the loss of aggregate particles from road surfacing. Porous asphalt in Netherlands and Malaysia face severe failure after several years of trafficking due to porous asphalt being a non-structural layer. The large and interconnected air voids of porous asphalt that hasten the ageing of binders will contribute to ravelling. When the thin film of binder which coats the aggregate particles reacts with oxygen from the air which readily occupies the large air voids, the binder rapidly becomes hard.

Clogging is the principal problem for porous asphalt. This is typically attributed to the amount of dirt, the size and structure of voids, and the cleaning effect of fast moving vehicles [6]. Permeability loss always accompanies clogging and when the extent of clogging is severe, all benefits associated with an open mix will disappear. According to Huber, Denmark has discovered that the air voids decreased by 3% to 4% in 2 years to approximately 18% [15].

Besides that, the service life of dense mix layers are longer than that of porous mix asphalt because of the binder content and type, aggregate gradation, climate and also traffic volume. Large air voids make the connection between aggregates weaker and thus induce the short service life of porous asphalt. Although the expected positive life is around 15 years, the maintenance for porous asphalt will normally be run every 5 to 8 years.

DLPA has been designed to slightly contrast with porous asphalt to overcome the weakness of porous asphalt. The smaller size of aggregates in the top layer can prevent dirt from entering the lower layers and hence the clogging can be solved easily by present technology. Besides that, the smaller sizes of aggregates in the top layers of DLPA provide better service life than porous asphalt since there are smaller interconnection air voids between aggregates.

1.3 The Objectives of the Study

The objectives of this study are as follows:

1. To determine the optimum percentage of CS and CF in DLPA.
2. To investigate the physical and chemical properties of CS and CF.
3. To investigate the performance of DLPA with CS and CF.

1.4 Scope of Work

All tests were carried out in the Highway and Transportation Engineering Laboratory of the School of Civil Engineering, Universiti Teknologi Malaysia (UTM) Skudai, Johor Bahru. When conducting the tests, a number of scopes were considered in this research.

The relative thickness of the top and base layer of the DLPA mix was fixed at 20/50 mm. Besides that, the aggregates that were used as base layers had a Nominal

Maximum Aggregate Size (NMAS) of 20 mm, the top layers had NMAS of 14 mm and the mix gradation relied on Malaysia Gradation. The top layer of the DLPA was modified by varying percentages of coconut shells and coconut fibres while the bottom layer of DLPA was not modified. The bitumen used was PG-76 and the design binder content (DBC) was based on Cantabro loss and binder drainage tests. In addition, the percentages of coconut shell used to replace the aggregate of 5 mm by weight at the top layers were 0, 5%, 10% and 15% while the coconut fibres used were 0, 0.3% and 0.5%.

1.5 Significance of Study

This study emphasised the feasibility of applying coconut shells and coconut fibres into DLPA towards reducing waste materials and increasing the properties of asphalt pavement. Since DLPA is revolutionizing the road surfacing technology, this study is important in order to discover new mixtures and enhance the performance of porous asphalt so that it can be used as a forward-looking surfacing technology in Malaysia. The significance of this research is as follows:

1. This study may reduce the discarded materials, coconut shells and coconut fibres and hence contribute towards a greener environment.
2. This design may contribute towards an enhanced porous pavement performance such as better cracking and clogging resistance.
3. When the performance of DLPA can be improved, it can be installed at field. Hence, the functions of DLPA can be carried out and the weaknesses of DLPA such as clogging and short service life may be improved upon.

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LIST OF PUBLICATION

YEAR	TITLE
2018	Tay Lay Ting, Ramadhansyah P.J, Norhidayah A.H, Haryati Y., M R Hainin, M H Wan Ibrahim, D S Jayanti and A M Abdullahi. Effect of Treated Coconut Shell and Fiber on the Resilient Modulus of Double-layer Porous Asphalt at Different Aging, IOP Conference Series: Earth and Environmental Science, Vol 140, Issue 1, P. 012065.
2017	Tay Lay Ting, Ramadhansyah P.J, Norhidayah A.H, Haryati Y. Resilient Modulus of Double Layer Porous Asphalt: Application of Alkali Treated Coconut Shell and Fibre as Aggregate Replacement, Malaysian Journal of Civil Engineering, Volume 29, Issue 2, Pp. 187-194.
2016	Tay Lay Ting, Ramadhansyah P.J., Norhidayah A.H., Haryati Y., Dewi S.J., Mohd Azreen M.A. A Review of Chemical and Physical Properties of Coconut Shell in Asphalt Mixture. Jurnal Teknologi (Sciences and Engineering), Volume 78, Issue 4, Pp. 85–89.
2015	Tay Lay Ting, Ramadhansyah P.J., Norhidayah A.H., Haryati Y., Dewi S.J. A Review of Utilization of Coconut Shell and Coconut Fibre in Road Construction. Jurnal Teknologi (Science and Engineering), Volume 76, Issue 14, Pp. 121–125.